

This electronic thesis or dissertation has been downloaded from the King's Research Portal at <https://kclpure.kcl.ac.uk/portal/>



Advances in the assessment and rehabilitation of older adult fallers

Liston, Matthew

Awarding institution:
King's College London

The copyright of this thesis rests with the author and no quotation from it or information derived from it may be published without proper acknowledgement.

END USER LICENCE AGREEMENT



Unless another licence is stated on the immediately following page this work is licensed

under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International

licence. <https://creativecommons.org/licenses/by-nc-nd/4.0/>

You are free to copy, distribute and transmit the work

Under the following conditions:

- Attribution: You must attribute the work in the manner specified by the author (but not in any way that suggests that they endorse you or your use of the work).
- Non Commercial: You may not use this work for commercial purposes.
- No Derivative Works - You may not alter, transform, or build upon this work.

Any of these conditions can be waived if you receive permission from the author. Your fair dealings and other rights are in no way affected by the above.

Take down policy

If you believe that this document breaches copyright please contact librarypure@kcl.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.

This electronic theses or dissertation has been downloaded from the King's Research Portal at <https://kclpure.kcl.ac.uk/portal/>



Title:Advances in the assessment and rehabilitation of older adult fallers

Author:Matthew Liston

The copyright of this thesis rests with the author and no quotation from it or information derived from it may be published without proper acknowledgement.

END USER LICENSE AGREEMENT



This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivs 3.0 Unported License. <http://creativecommons.org/licenses/by-nc-nd/3.0/>

You are free to:

- Share: to copy, distribute and transmit the work

Under the following conditions:

- Attribution: You must attribute the work in the manner specified by the author (but not in any way that suggests that they endorse you or your use of the work).
- Non Commercial: You may not use this work for commercial purposes.
- No Derivative Works - You may not alter, transform, or build upon this work.

Any of these conditions can be waived if you receive permission from the author. Your fair dealings and other rights are in no way affected by the above.

Take down policy

If you believe that this document breaches copyright please contact librarypure@kcl.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.

Advances in the assessment and rehabilitation of older adult fallers

By

Matthew Bryan Liston

2013

Centre of Human and Aerospace Physiological Sciences

School of Biomedical Sciences

King's College London

Submitted in partial fulfilment of the requirements of the Degree of Doctor of
Philosophy of King's College London

Abstract

This thesis attempts to answer a number of questions regarding falls in older adults, both in terms of the assessment of individuals experiencing falls and their physiotherapy based rehabilitation.

Firstly, an audit (Chapter 2) of a commonly used falls risk assessment tool (the Physiological Profile Assessment: PPA) was performed to determine the variability of component measures in differing age groups and to assess its clinical validity.

A novel multi-task directed stepping test was designed and piloted to investigate changes in volitional directed stepping when performing complex spatial tasks (Chapter 3). Changes in prioritisation of postural tasks with older age were identified in healthy older adults compared to a healthy young cohort.

A case control trial was performed to compare vestibular function in older adult fallers and age matched healthy individuals (Chapter 4). Both groups were compared to age matched patients with known peripheral vestibular dysfunction across a range of physical and questionnaire measures. It was identified that fallers have significantly higher proportions of vestibular dysfunction than age matched healthy older adults.

A 2 arm RCT was performed to investigate the beneficial effects of a customised multi-sensory balance home exercise rehabilitation programme

(vs. stretching) (Chapter 5). Older adult fallers undertook an 8 week Otago programme combined with either a Multi-sensory or Stretching home exercise programme. Multi-sensory rehabilitation provided significant within group and larger between group changes in FGA scores and PPA falls risk. This study identifies the beneficial effects of multi-sensory rehabilitation in older adult fallers, when combined with the Otago exercise programme.

Acknowledgements

First and foremost I would like to thank my supervisor Marousa Pavlou for everything she has done for me over the past years. Your patience, expert advice, amazing eye for detail and constructive yet supportive feedback has helped shape me into the researcher I am today, and has provided me with the drive and inspiration for the researcher I would like to be in the future. I look forward to working with you in the future to try and improve balance function for one and all!

Secondly I would like to thank Dr Jeroen Bergmann, for many afternoons and evenings of discussion. Your can-do approach, innate ability to make equipment and understand everything I say have made the process of prototyping and designing studies not only easy but fun also. I would also like to thank Dr Dave Green for invaluable help through-out the multi-tasking study and for always being there to talk about the quirks of physiology (amongst other things!).

I would also like to express a massive thank you to all in the department of neuro-otology at Queen Square. Specifically I would like to thank Prof. Luxon and Dr Doris Bamiou for their insight and assistance with planning and executing the pilot study. My biggest thanks are reserved for the audiology team; Albert, Karen, Nehzat, Fan and Olivia. You provided me with expert teaching, tea, a good ear when I needed someone to talk with and always made me feel so welcome within the department.

Without the enthusiasm and vocal support from clinical staff at Guy's and St Thomas' and the Whittington many of the studies would not have got off of the ground. I have to extend a huge amount of gratitude to Dr Finbarr Martin, who has been a massive influence from the outset. You have always shown a vast amount of interest in my work, provided enthusiastic support at the right times and have

always provided feedback with such incredible insight. If I hadn't worked with you in 2007 this PhD may never have come about.

At King's I would like to thank Tony, Lindsey and Helen for helping me find a home for my classes, always being flexible and encouraging me to try new things. To all my colleagues within CHAPS, thank you so much for being there, always being willing to be a guinea pig and listening to my endless presentations. Special thanks have to go to Ross Pollock, the font of all knowledge, Sally Rosenvinge (or should I say Archer!) for always wanting a cup of tea and always providing excellent advice on everything from presentations to dinner recipes, Mel Fleming for cooking far too many dinners for me and always being willing to go for a post work beer and last but not least to Marniza Omar, words cannot describe how amazing you are (or how good the Malaysia Hall is!). Not long to go now Mar, good luck!

Finally I would like to thank my mum and dad for all the support they've given me over the years, I'm still not sure if you know what I do, but I don't mind and I promise I won't bore you with this stuff anymore.

Saving the best till last..... I owe the biggest debt of gratitude to Carolyn, my beautiful girlfriend who has kept me sane over the course of the PhD. Thank you for being so amazing, I can't put into words how much you have done for me over the years and how unbelievably lucky you make me feel every day. The only way I could feel any better would be if you answered this one question..... *Will you marry me?*



(Ring for illustration purposes only)

Table of Contents

Abstract	2
Acknowledgements.....	4
Table of Contents	6
Table of Figures.....	10
Table of Tables.....	12
Chapter 1. Literature review	13
1.1 General Introduction.....	13
1.2 Falls	13
1.2.1 Epidemiology of Falls.....	13
1.2.2 Common risk factors for falls.....	15
1.2.3 Activity levels and falling	24
1.2.4 Location of falls.....	25
1.2.5 Physical effects of falls.....	26
1.2.6 Psychosocial effects of falls	28
1.2.7 Cost of falls	29
1.2.8 Legislation for falls	29
1.3 Postural Control	31
1.3.1 Sensory components of the balance system.....	34
1.3.2 Postural control in older adults.....	40
1.3.3 Changes in the vestibular system with age	42
1.3.4 Vestibular function and falls in older adults	45
1.4 Measuring falls risk in older adults.....	47
1.4.1 Static Measures	48
1.4.2 Dynamic Measures	49
1.5 The Rehabilitation of Older Adult Fallers	52
1.5.1 Current Practice in Falls Rehabilitation	52
1.5.2 Novel Approaches to therapy	58
1.6 Aims of thesis.....	64
Chapter 2. The Physiological Profile Assessment: Clinical validity of the postural sway measure and comparison of impairments by age.....	66
2.1 Abstract.....	66
2.2 Introduction	68
2.3 Methods	70
2.3.1 Statistical analysis.....	71
2.4 Results	73

2.4.1 Gender comparisons.....	73
2.4.2 Comparisons according to age group	73
2.4.3 Comparisons according to ability to perform sway test.....	75
2.5 Discussion.....	78
2.5.1 Differences in PPA test measures and variability between age groups ..	78
2.5.2 Clinical validity of the PPA sway measure.....	81
2.6 Conclusions.....	82
Chapter 3. A complex bi-modal spatial multi-task alters postural prioritisation in healthy older adults.....	84
3.1 Abstract.....	84
3.2 Introduction	86
3.3 Materials and Methods	89
3.3.1 Participants.....	89
3.3.2 Experimental apparatus and techniques	90
3.3.3 Task ordering.....	92
3.3.4 Visual Coded Spatial Task (VS) (Stepping task)	92
3.3.5 Auditory Coded Spatial Task (AS).....	93
3.3.6 Data Recording.....	93
3.3.7 Statistical Analysis	94
3.4 Results.....	95
3.4.1 Response times	95
3.4.2 Task Accuracy	100
3.5 Discussion.....	102
3.5.1 Effects of task complexity.....	102
3.5.2 Effects of Attention switching	105
3.5.3 Postural control and implications for practice	107
3.5.4 Study limitations.....	108
3.6 Conclusion	108
Chapter 4. A comparison of balance, dizziness, and falls risk in older-adult fallers and age-matched patients with a peripheral vestibular disorder: A pilot study.....	109
4.1 Abstract.....	109
4.2 Introduction	111
4.3 Materials and Methods	113
4.3.1 Subjects:.....	113
4.3.2 Neuro-otologic Assessment	114
4.3.3 Balance and Gait Measures.....	114
4.3.4 Questionnaires:.....	115
4.3.5 Falls History	117
4.3.6 Statistical Analysis	117
4.4 Results.....	118

4.4.1 Demographics.....	118
4.4.2 Prevalence of vestibular dysfunction.....	118
4.4.3 Physical measures.....	121
4.4.4 Subjective questionnaire data	124
4.4.5 Correlations	127
4.5 Discussion.....	127
4.5.1 Vestibular Function	128
4.5.2 Physical measures.....	129
4.5.3 Subjective Symptoms	131
4.5.4 Implications for practice	134
4.6 Conclusions.....	135
Chapter 5. The effect of OTAGO exercises with and without multi-sensory rehabilitation exercise on falls risk, gait, and balance confidence in older adult fallers: A pilot randomised control trial	137
5.1 Abstract.....	137
5.2 Introduction	139
5.3 Material and Methods.....	141
5.3.1 Participants.....	141
5.3.2 Allocation.....	142
5.3.3 Intervention.....	144
5.3.4 Outcome measures.....	148
5.3.5 Statistical analysis.....	151
5.4 Results	152
5.4.1 Assessment at Week 4	153
5.4.2 Final Assessment	153
5.4.3 Between Group Differences	153
5.4.4 Within Group Differences	156
5.4.5 Correlation Analysis	160
5.4.6 Reported falls during study and at 6-month follow-up.....	160
5.4.7 Participation and drop-out.....	161
5.4.8 Serious Adverse Events.....	161
5.4.9 Power Calculation for Future Study.....	161
5.5 Discussion.....	161
5.5.1 Physical measures.....	162
5.5.2 Visual Measures	166
5.5.3 Subjective measures.....	168
5.5.4 Implications for practice	169
5.6 Conclusions.....	170
Chapter 6. Discussion	171
6.1 Context of project	171

6.2 The assessment of older adult fallers	172
6.2.1 Physical measures.....	172
6.2.2 Subjective symptoms in older adults	175
6.2.3 Dual tasking ability / multi tasking in healthy older adults	176
6.2.4 Clinical measures of vestibular function	177
6.3 The rehabilitation of fallers	179
6.3.1 Changes in physical measures of falls risk.....	180
6.3.2 Changes in subjective symptoms.....	181
6.3.3 Clinical Implications and planned service changes.....	182
References	184
Appendix 1. Bimodal spatial multi-tasking significantly increases response times in healthy adults.....	197
Appendix 2. Supplementary data analysis for chapter 3	211
Appendix 3. Screening for Dual Processing Study.....	217
Appendix 4. INFORMATION SHEET FOR PARTICIPANTS	221
Appendix 5. Instructions for bi-modal spatial multi task test	225
Appendix 6. INFORMATION SHEET FOR PARTICIPANTS	228
Appendix 7. Consent Form	233
Appendix 8. INFORMATION SHEET FOR PARTICIPANTS	235
Appendix 9. The OTAGO Exercise Programme.....	240
Appendix 10. Outcome Measures.....	242
Functional Gait Assessment (FGA).....	242
Appendix 11. Examples of a home exercise programmes	253
Appendix 12. Vestibular Pathway for Fallers.....	259
Appendix 13. The Physiological Profile Assessment: Clinical Validity of the postural sway measure and comparison of impairments by age. European Geriatric Medicine.	260

Table of Figures

Figure 1.1 Model representing systems contributing to postural control.....	31
Figure 1.2 Demonstration of the hip, ankle and step strategies in the anterior direction.....	33
Figure 1.3: The organisation of the vestibular apparatus.....	36
Figure 2.1 Diagrammatic representations of component tests of the PPA.....	70
Figure 2.2 Plot of mean standard deviation (95% CI) of the Z scores computed for the five composite Physiological Profile Assessment tests.....	75
Figure 3.1 Diagrammatic representation of the experimental set up for the stepping task.....	91
Figure 3.2 Raw dual task cost data individual level data according to task priority in older adults (A/B) and younger adults (C/D).....	98
Figure 3.3 Median (IQR) Dual Task Costs for response time in the Visuo-Spatial and Audio-Spatial tasks for younger and older adults.	99
Figure 3.4 Median (IQR) Dual Task Costs for response accuracy in the Visuo-Spatial and Audio-Spatial tasks for younger and older adults.....	101
Figure 4.1 Mean (95% CI) score on the Functional Gait Assessment.	122
Figure 4.2 Mean (95% CI) for vestibular (VSS-V) and somatic anxiety (VSS-A) symptoms as measured by the Vertigo Symptom Scale	125
Figure 5.1 Flow chart of participants through the trial.....	143
Figure 5.2 Mean Functional Gait Assessment (95% CI) scores at baseline, week 4 and week 8.	156
Figure 5.3 Mean (95% CI) for Physiological Profile Assessment Scores at baseline, week 4 and week 8.....	157
Figure 5.4 Mean (95% CI) scores for Vertigo Symptom Scale Vestibular subscale at baseline, week 4 and week 8.....	158
Figure 5.5 Mean (95% CI) for Activities Specific Balance Confidence Scale scores at baseline, week 4 and week 8.....	159

Figure 0.1 Median (IQR) dual task costs (DTC) for response time in the visuo-spatial (VS) and audio-spatial (AS) tasks for younger and older adults.	214
Figure 0.2 Median (IQR) dual task costs (DTC) for response accuracy in the visuo-spatial (VS) and audio-spatial (AS) tasks for younger and older adults.	216

Table of Tables

Table 2.1 Median scores and ranges for all subjects according to age group for component tests of the PPA, PPA falls risk and number of self reported falls in the previous 12 months.....	74
Table 2.2: Median scores and ranges of PPA measure scores, age and previous falls for all subjects according to ability to perform the Sway test of the PPA.....	77
Table 3.1 Mean (\pm SD) response time (s) and accuracy (%) for single task and dual task conditions for younger and older adult groups.....	97
Table 4.1 Proportions of vestibular diagnoses for each subject group.....	120
Table 4.2 Mean (SD) scores for physical measures.	123
Table 4.3 Mean (SD) scores for questionnaire data.....	126
Table 5.1 Summary of exercises used for Multi-Sensory Home Exercise Programme	147
Table 5.2 Mean (SD) values for baseline data collected for all recruits	152
Table 5.3 Mean (SD) scores for physical outcome measure.	154
Table 5.4 Mean (SD) for questionnaire data.	155
Table 0.1 Mean (SD) response times (s) and accuracy (%) for single and dual task conditions for younger and older adults with error rates less than 50%.....	213

Chapter 1. Literature review

1.1 General Introduction

Approximately one third of adults over 65 fall annually (Blake et al. 1988); with falls being a leading cause of injury and mortality in this group (Nevitt et al. 1991; Lord et al. 1992; Lehtola et al. 2006). Falls are commonly associated with physical impairments, poor balance control and altered gait. Fall rates can be reduced by appropriate assessment and rehabilitation; reducing falls rate by up to 40% in targeted populations (Robertson et al. 2002). This PhD thesis investigates the assessment of falls risk in older adults and rehabilitation for older adult fallers. Specifically, the included studies investigate a) the validity of the physiological profile assessment (Lord et al. 2003); a commonly used falls risk assessment tool, b) complex multi-tasking ability in older adults, c) clinical balance function, and self reported measures in fallers and d) multi-sensory rehabilitation of older adult fallers. The purpose of this introductory chapter is to provide a background for the specific studies included in the thesis and will include: falls, factors affecting postural control, falls risk assessment and rehabilitation.

1.2 Falls

1.2.1 Epidemiology of Falls

There is no accepted definition of a fall. Therefore for the purpose of this thesis a fall will be defined as “unintentionally coming to the ground or some lower level other than as a consequence of sustaining a violent blow, loss of

consciousness, sudden onset of paralysis as in stroke or seizure” (Kennedy and Coppard 1987).

Falls pose a major threat to the well being and quality of life of older adults. It is widely accepted that approximately 1/3 of all older adults experience one or more falls annually, around half of which experience more than one (Blake et al. 1988; Tinetti et al. 1988; Lord et al. 1993; O'Loughlin et al. 1993; Luukinen et al. 1994; Lord and Clark 1996; Salva et al. 2004), with rate increasing with age both for single and multiple falls. This increase in falls exposure is highlighted by Gribbin et al (2009) where reported rates for multiple falls were 55 times higher in individuals aged 90+ years compared to 60-64 year olds and 15 times higher for single falls. However, this large UK study only examines falls reported in computerised medical records from primary care, and as such falls firstly need to be recalled and then reported to the clinician. Retrospective recall of falls is less sensitive than prospectively collected data (Ganz et al. 2005), and when combined with actual reporting of all falls to primary care clinicians may explain the lower falls rate in this study compared to prospectively collected data (Luukinen et al. 1994; Lord and Clark 1996; Salva et al. 2004). This study does identify largely elevated falls rates in older adults: however, due to the method of data collection it may actually be underestimating the enormity of the problem that is falls in older adults.

1.2.2 Common risk factors for falls

1.2.2.1 Age

A major risk factor for falls is age, with risk increasing with advancing years (Scuffham et al. 2003; Gribbin et al. 2009). Age related declines in function of peripheral sensory systems (visual, vestibular, proprioceptive) and central integrators have been identified and are associated with increased falls risk (Lord et al. 1991; Baloh et al. 2001; Redfern et al. 2001; Woollacott and Shumway-Cook 2002; Baloh et al. 2003). The changes in these functions with age, their impact on postural control and their contribution to falls will be discussed further in section 1.3.

As individuals progress into later older age individuals become frailer, less likely to mobilise outdoors and have a higher risk of peripheral skeletal fractures following a fall. The increase in fracture rate is due to both a higher prevalence of osteoporosis and rate of falling, therefore increasing exposure (Gerdhem et al. 2005). The change in location of falls and types of injury will be discussed in sections 1.2.4 and 1.2.5 respectively.

1.2.2.2 Previous falls

When attempting to diagnose the causes of falling, single falls are often considered isolated events, as they are less predictable and have an increased likelihood of being due to an accident or overwhelming incident (Lord et al. 1991). However, multiple fallers are more likely to have

underlying neurological or musculoskeletal pathology (Nevitt et al. 1989; Lord et al. 1991; Lord and Ward 1994; Lord et al. 1994) which would be beneficial to identify and treat if possible to try to prevent future falls.

A fall within the past 12 months is a significant predictor of falls within the next 12 months, with multiple fallers having significantly elevated risk for future falls compared to single and non-fallers (Nevitt et al. 1989; Papaioannou et al. 2004; Gerdhem et al. 2005). Single and multiple falls in women aged over 75 increase the odds for future falls by 2.01 and 3.88 respectively (Gerdhem et al. 2005). Therefore, the need for an accurate representation of falls history is crucial. Those that experience an injurious fall, increase their odds of having multiple falls in the following year by 3.1 times compared to a non-faller (Nevitt et al. 1989), and similarly multiple fallers (five or more) are 7.9 times more likely to suffer major injury than a single faller (Nevitt et al. 1991).

1.2.2.3 Gender

Not only does fall frequency increase with age, but rates are significantly higher in females than in males; with a concomitant increase in risk of injurious falls in women (Nevitt et al. 1991; Lord and Ward 1994). This elevated injury risk in females can be observed in hospital admissions, which increase consistently in older age at a rate of 4.9% per annum in males and by 7.9% per annum in females (Lord 1990).

Specific gender differences have been observed in performance of physical and psychological tests, which may in part explain increased fall rates in women. Studies have identified lower levels of reported anxiety, less dependence on visual cues for postural orientation, greater quadriceps strength, better static postural control and gait in complex situations in older males compared to females (Lord and Ward 1994; Herman et al. 2008). Lower reported anxiety (which can modify postural responses (Yardley 2004)) when coupled with greater static and dynamic postural control provide a rationale for lower falls rates in older males.

1.2.2.4 Clinical history

Older people with multiple chronic illnesses or falls risk factors have a higher frequency of falling than active people with no known pathology or impairment (Tinetti et al. 1988; Stalenhoef et al. 2002; Gerdhem et al. 2005). In a study of older adults reporting at least one fall in the previous year, lower limb arthritis increased the risk of multiple falls in the following year by 2.7 times (Nevitt et al. 1989) compared to individuals without lower limb pathology. This may be due to decreased stability secondary to reduced muscle strength resulting from reduced mobility (Campbell et al. 1989), pain and impaired joint motion (Nevitt et al. 1989) or altered proprioception due to mechanical deformation of the joint. Neurologic conditions more common in older age such as stroke or Parkinson's Disease can affect strength, awareness and orientation, all of which are essential for postural control and therefore can increase the likelihood of falls. A previous clinical history of stroke increases the incidence of falls in community-dwelling older adults by

2.4 and 1.8 times in women and men respectively (Campbell et al. 1989; O'Loughlin et al. 1993) and Parkinson's Disease increases falls risk by 9.5 times compared to healthy controls (Nevitt et al. 1989).

The number and type of medications taken can also affect fall rate and risk in older adults. Falls risk increases by approximately 30% when taking multiple medications (4+) (Bath and Morgan 1999; Gerdhem et al. 2005), and is an indicator for frailty (Tinetti et al. 1988). Regarding specific medications, diuretics and anti-hypertensives may cause fluctuations in blood pressure which could lead to syncopal falls. Psycho-active medication increase the odds of falling by 2.07 times (Gerdhem et al. 2005), with sedatives increasing risk for falls by 1.5 - 2.5 times, most likely by affecting levels of arousal. Psychoactive medications are independent predictors for falls when controlling for the condition they have been prescribed for (Tinetti et al. 1988; Nevitt et al. 1989).

1.2.2.5 Dizziness

Postural control is a complex task where multiple systems are utilised to maintain stability (see section 1.3). For successful postural control a person needs to be able to orient individual body segments with respect to internal references, gravity, the support surface and the visual environment (see Figure 1.1) (Horak 2006). Dizziness is an umbrella term which encompasses sensations of vertigo, disequilibrium, presyncope and light headedness (Reilly 1990) and can cause symptoms of spatial disorientation and unsteadiness. Dizziness is a well-recognised problem in older adults with

prevalence rates ranging from 11% to 30% in community dwelling older adults; with unsteadiness and vertiginous symptoms (i.e. sensations of spinning or moving) amongst the most commonly reported (Colledge et al. 1994; Tinetti et al. 2000; Stevens et al. 2008). Symptoms are commonly associated with postural changes such as rising to stand from supine (40-50%), looking up (29%) and turning the head to the side (29-41%) (Colledge et al. 1994; Tinetti et al. 2000). Individuals that report dizziness are more likely to experience postural hypotension, cardiac arrhythmia, anxiety and have impaired static standing balance, gait asymmetry and increased deviation when walking (Colledge et al. 1994; Tinetti et al. 2000; Stevens et al. 2008). None of these cross sectional studies assessed vestibular function or sensory integration ability. This may have provided insight into: a) the reduced ability to maintain static balance and impaired gait function and b) symptoms brought about by both postural changes and head movements. Dizziness when changing position or turning the head when standing / walking may lead to postural disturbances and falls.

Vertiginous symptoms are significantly more common in older adult fallers compared to non-fallers (Prudham and Evans 1981), and in a recent systematic review with meta-analysis vertiginous symptoms provided increased odds for single and multiple falls by 1.8 and 2.3 times respectively (Deandrea et al. 2010). Dizzy symptoms can be due to a number of potential causes including medication use, cardiac dysfunction, vestibular dysfunction and anxiety. Due to its multiple causes and association with falls, dizziness

has been postulated as a geriatric syndrome that needs to be managed effectively (Tinetti et al. 2000)

1.2.2.6 Cognitive Function

The presence of impaired cognitive function increases the likelihood of falls in older adults, even in mild deficiencies. Gleason et al (2009) observed an increased falls rate ratio of 1.2 for every 1 point decrease in Mini Mental State Exam in individuals at risk for falls. Other studies have shown that cognitive impairments, (identified by scores <5 in the short portable mental status questionnaire) increase the odds of falling by 5 times in community-dwelling ambulatory adults over the age of 75 (Tinetti et al. 1988).

Physically, older adults with cognitive impairment exhibit greater postural sway than non-impaired adults and have greater falls risk as measured by the Physiological Profile Assessment, which measures factors including reaction time, proprioception and strength (Liu-Ambrose et al. 2008). Impaired cognitive function may expose individuals to increased falls risk due to impairments in judgement, risk perception, poor attention and / or executive function that may predispose them to perform unsafe tasks or to perform them in an unsafe manner (Gleason et al. 2009). Furthermore, older adults with cognitive decline (MMSE <19) have also been shown to experience markedly reduced benefits from a multi-factorial intervention aimed at reducing falls, as falls rate is not significantly reduced post-intervention compared to older adults with higher MMSE scores (Jensen et al. 2003). However, this cluster randomised trial was not blinded, and groups

were not matched by age, physical impairments, functional limitations or drug use and the authors suggest that treatment sessions within the cognitively impaired group may not have been suitably challenging or particularly well adhered to. However, improvements in muscle strength, gait speed and stair climbing power, all factors associated with falls risk, have been demonstrated in cognitively impaired older adults following an exercise regime focusing on progressive resistance training. However falls rate was not recorded in this study and therefore the treatment effect on this cannot be determined (Fiatarone et al. 1994).

1.2.2.7 Mobility and transfer status

Functional mobility includes the ability to stand, transfer or mobilise. A functional decline in any of these parameters increases falls risk. Many factors can affect a person's ability to rise from a chair, including lower limb strength, body weight, proprioception, reaction time, anxiety and perceived pain (Schenkman et al. 1996; Lord et al. 2002). Difficulties in standing from sitting in a chair (i.e. > 2 seconds) increase the odds for multiple falls by three times compared to those experiencing no difficulties (Nevitt et al. 1989). Individuals able to rise from a chair but unable to stand unaided are most likely to fall. However, injurious falls are more likely to occur in those that can rise and stand unaided but have multiple falls risk factors (Lord et al. 2003).

Limitations in functional activities of daily living (ADL's) can increase the risk of experiencing either a single or multiple falls by 2.9 and 4.3 times

respectively (Graafmans et al. 1996); with self-reported difficulties in bending down increasing the risk for falls by 1.4 times (O'Loughlin et al. 1993). Limitations in bending down may be due to a number of reasons, such as mechanical constraints, reduced confidence, benign paroxysmal positional vertigo and poor postural control. In a large scale community study in the North East of England, significantly higher proportions of fallers were found to express difficulties with getting out of bed, dressing themselves and mobilising indoors, indicating high levels of dependency and frailty in this falling group (Prudham and Evans 1981).

As expected gait abnormalities are independent predictors for falls in older adults (Tinetti et al. 1988; O'Loughlin et al. 1993; Gunter et al. 2000; Hausdorff et al. 2001). As a result many clinical measures have been designed to assess gait in older adults at risk for falls. Commonly used assessments investigate gait technique (e.g. step symmetry, length, height) (Tinetti 1986), speed (Podsiadlo and Richardson 1991) and ability to modify gait to specific tasks such as stepping over objects and turning the head left to right (Shumway-Cook et al. 1997; Wrisley and Kumar 2010). Fallers typically display abnormalities within the normal gait cycle including uneven step length and timing, slower speed and alterations in gait, or cannot perform the task (Clark et al. 1993; Shumway-Cook et al. 1997; Shumway-Cook et al. 2000; Hausdorff et al. 2001; Wrisley and Kumar 2010). When walking, fallers also exhibit a reduced ability to control head and pelvis accelerations (Hirasaki et al. 1993; Menz et al. 2003), which may have

implications both for visual acuity when walking (and therefore obstacle avoidance) and control of centre of gravity.

1.2.2.8 Dual Tasking

Postural control requires attention (see Figure 1.1), with the amount of attention provided affecting a person's ability to effectively adapt to, or integrate sensory information (Redfern et al. 2001; Teasdale and Simoneau 2001). Performing multiple tasks simultaneously such as walking and talking are the norm in daily life and require the allocation of attention between tasks to perform successfully, with the amount of attention required varying with the inherent difficulty of the tasks (Shumway-Cook et al. 1997; Woollacott and Shumway-Cook 2002). The posture first strategy hypothesises that when dual-tasking, the postural task will be prioritised if task demands are high (Shumway-Cook et al. 1997; Brauer et al. 2002). Although greater deterioration in the cognitive task is expected according to the posture first strategy, dual-tasking may also have detrimental effects on postural stability. General effects of dual tasking include slower response times, reduced accuracy, gait speed and/or step length and greater postural sway (Lajoie et al. 1996; Brauer et al. 2002; Toulotte et al. 2006; Sturnieks et al. 2008).

Age has a significant effect on a person's dual-tasking ability, with older adults significantly more affected than younger adults in all postural conditions (standing, stepping and walking) (Maylor and Wing 1996; Shumway-Cook et al. 1997; Teasdale and Simoneau 2001; Brauer et al. 2002; Alexander et al. 2005; Dommès and Cavallo 2011). These deficits in

dual-task ability may put an individual at increased risk for falls, and indeed individuals with a history of falling perform significantly worse than non fallers in dual-task conditions (Shumway-Cook et al. 1997; Brauer et al. 2002; Siu et al. 2009; Hawkes et al. 2011). In a simple clinical measure of dual-tasking (walking whilst talking), being unable to perform the two tasks simultaneously predicts future falls with a sensitivity of 95% and specificity of 48% (Lundin-Olsson et al. 1997).

The type of secondary task also plays a role; with spatial tasks having a greater impact on postural control compared to verbal tasks performed in standing and stepping. Spatial tasks increase response times, postural sway and falls both in healthy older and younger adults compared to non-spatial tasks (Barra et al. 2006; Sturnieks et al. 2008; Woollacott and Vander Velde 2008). These may have a significant effect on postural stability when performing functional activities such as mobilising through crowds or navigation.

1.2.3 Activity levels and falling

Salva et al (2004) described a 'U' shaped relationship between activity levels and falls rate whereby the least at risk group was participating in light activity, while those at either end of the spectrum i.e. sedentary or very active had increased falls risk. Maintaining an active lifestyle may be protective against future falls in older adults due to preservation of vestibular function, strength, function and co-ordination but may also increase the likelihood of falls, especially in the very active younger elderly due to an increase in risk

exposure (O'Loughlin et al. 1993; Salva et al. 2004). Older adults that maintain physical activity into retirement show greater vestibular symmetry in both the Fitzgerald Hallpike bithermal caloric test and rotation testing, better proprioception and lower reaction times than those that have ceased (Gauchard et al. 2003; Gauchard et al. 2004) indicating better postural control and a reduced falls risk. Although regular exercise is obviously beneficial to maintaining function and limiting multiple falls risk factors, regular outdoor walking can increase the risk for outdoor falls by increasing exposure (Bath and Morgan 1999; Li et al. 2006).

1.2.4 Location of falls

As individuals age not only does the frequency of falls, injurious falls and rate of admission to hospital change, but the location of falls also changes. Younger older adults tend to fall outside and older, frailer adults experience more indoor falls. Falls outside of the home are associated with younger age, increased activity levels and environmental factors such as ice, uneven paving, curbs or stairs (Bath and Morgan 1999; Li et al. 2006) and are most commonly reported whilst walking, with total outdoor walking time being a significant risk factor for outdoor falls (Bath and Morgan 1999; Li et al. 2006). In older adults the most common outdoor falls environment is the home garden, which accounts for nearly 50% of all outdoor falls (Li et al. 2006) and approximately 72% of all falls in under 75's (Bath and Morgan 1999). Outdoor falls however are not associated with mobility limitations and do not increase mortality risk when compared with age-matched community-dwelling non-fallers (Bath and Morgan 1999; Manty et al. 2009).

Indoor falls account for between 50% (over 75's) and 75% (over 85's) of all falls in elderly older adults (Blake et al. 1988; Nevitt et al. 1989; Bath and Morgan 1999) and are associated with frailty, older age (Blake et al. 1988) female sex (Campbell et al. 1990), reduced outdoor mobility and activity levels (Manty et al. 2009). Factors such as muscle weakness (Bath and Morgan 1999), poor reaction times and poor static standing balance (Manty et al. 2009) indicate intrinsic rather than external environmental causes, which are responsible for outdoor falls. These factors may be remediable by appropriate intensity and targeted rehabilitation, although previous studies have shown mixed effects in reducing falls rate in frailer older adults (Campbell et al. 1999; Lord et al. 2005). The progression to falling indoors significantly impacts on mobility with indoor fallers having a three-fold increase in risk of mobility limitations at 3 years post fall (Manty et al. 2009).

1.2.5 Physical effects of falls

Injuries sustained due to a fall are of major concern to older adults and healthcare providers alike. The number of injurious falls increases with age rising steadily from age 60 (Campbell et al. 1990; Lord et al. 1993; O'Loughlin et al. 1993; Lord et al. 1994; Hoidrup et al. 2003) and can have a multitude of physical and psychological manifestations ranging from low level trauma to fractures, activity restriction and fear of falling. Lower level traumas such as contusions, lacerations and bruising have incident rates which vary from 37% to 63% in older adults (Campbell et al. 1990; Nevitt et al. 1991; Salva et al. 2004; Talbot et al. 2005).

The rate of serious injury, most notably a fracture following a fall, changes with age as does the location of the fracture itself. Up to 75 years of age, distal forearm fractures are more common, accounting for approximately 40% of all fractures (Graafmans et al. 1996; Hoidrup et al. 2003). However, although the rate of distal forearm fractures remains fairly constant throughout old age, the rate of hip fracture increases with increasing age (Graafmans et al. 1996; Kelsey and Samelson 2009). Neck of femur fractures become the predominant fracture site after age 75, with the risk of hip fracture following a fall in individuals aged 85 or over being 9.5 times higher than individuals under age 75 (Graafmans et al. 1996; Hoidrup et al. 2003). Hip fractures have been estimated to occur in 0.4 to 2% of all falls in community-dwelling adults over the age of 65 (Nevitt et al. 1991; Frick et al. 2010). They are associated with high mortality rates within 3 months post fracture, decreased function and independence, and an increased need for costly clinical care and rehabilitation facilities (Stalenhoef et al. 2002). Serious injurious falls can increase the likelihood of long-term admission into a skilled nursing facility by over ten times, incurring great cost to the individual and / or healthcare provider (Tinetti and Williams 1997).

Fall rate also increases mortality. Multiple falls increase the likelihood of death (Campbell et al. 1990; Dunn et al. 1992; Donald and Bulpitt 1999; Gribbin et al. 2009) by 2.2 to 2.6 times at 1 year and by 1.9 times 3 years (Dunn et al. 1992; Donald and Bulpitt 1999). However, when adjusting for presence of multiple pathologies and functional disability, mortality ratios lose

significance when comparing non-fallers to either single or multiple fallers (Dunn et al. 1992). Therefore indicating mortality may be a result of the predisposing factors for the fall associated with disease states rather than the fall itself. Mortality rates have been reported as significantly higher in older fallers (85 years +) who are also forty times more likely to die post fall than individuals under 65 (Hill et al. 2002). However, as the authors did not differentiate between single and multiple fallers, the contribution of multiple falls to mortality rate cannot be assessed.

1.2.6 Psychosocial effects of falls

Falls may greatly impact the well-being of older adults with both psychological and social effects. Both injurious and non-injurious falls may result in a 'post-fall syndrome' (Murphy and Isaacs 1982; Lord et al. 1992) whereby individuals experience a loss of confidence, hesitancy, tentativeness and a concomitant loss of mobility and independence (Clark et al. 1993). However, fear of falling is not exclusive to fallers. It can also be experienced by any older adult (Myers et al. 1996) with those reporting high levels of fear of falling, having greater difficulties with ADL's and worse physical function as measured on the SF-36 scale (e.g. kneeling, stooping, climbing stairs) (Cumming et al. 2000). Thus techniques to improve balance self confidence may have beneficial effects not only on confidence but in physical function.

1.2.7 Cost of falls

Older adults enrolled in Medicare schemes in the US that suffer a fall serious enough to require medical attention, create much higher costs to healthcare providers as compared to non-fallers in the 12 months following their fall (Bohl et al. 2010). A cost of illness study analysed the UK department of trade and industry statistics to determine the cost of treatment of serious falls in older adults (requiring a visit to Accident and Emergency). It was estimated that falls cost the National Health Service (NHS) and partner organisations nearly £1 billion in 1999, 66% of which was attributable to adults over the age of 65 (Scuffham et al. 2003). Hip fractures are the commonest serious injury following a fall occurring in approximately 2% of all falls (Nevitt et al. 1991) and affect approximately 60,000 people in the UK annually, costing the NHS approximately £2billion and resulting in approximately 14,000 deaths (Healthcare Quality Improvement Partnership 2008; Healthcare Quality Improvement Partnership 2011).

1.2.8 Legislation for falls

Due to the physical, psychological and economic impacts of falls in older adults (Lord et al. 1992; Lord et al. 1994; Masud and Morris 2001; Scuffham et al. 2003) the National Service Framework for Older People (NSF) (Department of Health 2001) identified the management of falls as one of eight core standards for the NHS in England. The American and British Geriatrics Society (AGS/BGS) released guidelines in 2001 complementary to the NSF (updated in 2010), to provide clinicians and falls clinics with a

framework within which to provide assessment and intervention for fallers. The NSF was supported and extended upon by the National Institute for Clinical Excellence (NICE) (2004) in providing detailed clinical guidance on assessment and interventions. Following these recommendations healthcare providers were tasked to create multi-disciplinary falls clinics to conduct falls risk assessments and implement targeted interventions for fallers.

The AGS/BGS recommend that every older adult should be asked if they have fallen annually, and if so, screened using a gait and balance test such as the Timed Up and Go Test (TUAG) (Mathias et al. 1986; Podsiadlo and Richardson 1991). The TUAG is recommended as a screening tool for multiple reasons. It is quick to complete, demonstrates high inter-rater reliability and concurrent validity with a number of assessment tools and is sensitive in differentiating fallers from non fallers (Podsiadlo and Richardson 1991; Shumway-Cook et al. 2000; Whitney et al. 2005). Those that experience difficulty or demonstrate unsteadiness should undergo multifactorial assessment to determine possible causes and to assist in targeting interventions (American Geriatrics Society et al. 2001; American Geriatrics Society and British Geriatrics Society 2010). Current AGS / BGS guidelines recommend that a falls assessment including vision, gait, balance and lower extremity joint function should be performed (American Geriatrics Society and British Geriatrics Society 2010) and that interventions tailored to each patient's need are provided. Currently no specific treatment intervention is recommended.

1.3 Postural Control

Biomechanical principles dictate that balance occurs when the line of gravity falls within the base of support. Stability is improved by increasing the base of support, lowering the centre of gravity and increasing mass (Bell 1998). Postural control is a complex function requiring the coordinated interaction of many musculoskeletal and neural systems including afferents from the visual, vestibular and somatosensory systems (Vouriot et al. 2004; Horak 2006) (Figure 1.1). Weighting of constituent afferents can be altered according to the goals of the movement task and the environmental context (Horak 2006). Postural control is associated with restoring the line of gravity to within the base of support to sustain a posture (e.g. standing) and to provide volitional and automatic postural movements.

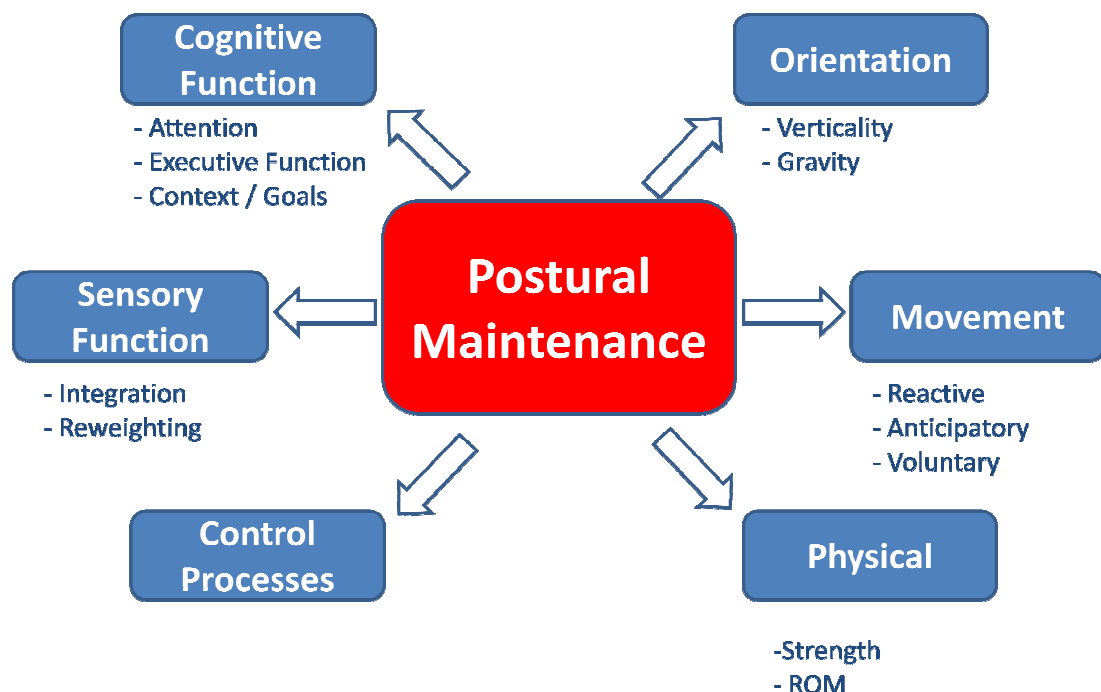


Figure 1.1 Model representing systems contributing to postural control (Adapted from Horak, 2006)

Maintaining postural equilibrium requires controlling the centre of gravity in relation to the base of support. Limits of stability are determined by the area over which a person can move their centre of gravity without altering the base of support. Physical factors such as adequate strength and range of movement are required to generate sufficient activity to counteract the effect of gravity. These physical factors prevent a fall when the centre of gravity exceeds the limits of stability in quiet standing (Horak 1987). Mobilising or changing position requires control of the centre of gravity outside of the base of support and therefore control processes are required to maintain stability (Winter et al. 1993). For example when mobilising, the swing leg is placed under the moving centre of gravity to provide anterior stability in gait, with lateral stability provided by lateral trunk control and foot placement (Bauby and Kuo 2000).

When moving a limb or lifting an object the centre of gravity is moved and anticipatory postural adjustments are made to maintain the centre of gravity within the base of support. When experiencing an external perturbation, three main types of reactive movement strategies are used to maintain postural stability, namely the ankle, hip and stepping strategies (Figure 1.2) (Horak 1987; McIlroy and Maki 1996). The ankle and hip strategies both move the centre of gravity whilst not adapting the base of support. However, the step strategy, which requires either an anterior/posterior or lateral step is the only movement strategy effective in preventing a fall when the centre of gravity is displaced beyond the limits of stability. The ankle strategy is more effective for small perturbations and when the support surface is firm,

whereas the hip strategy is more effective when larger, or fast perturbations occur or if the support surface is compliant (Horak and Nashner 1986). The step strategy is normally utilised when large perturbations occur and the centre of gravity is beyond the base of support. However, in older adults the step response has been identified when the centre of gravity is within the limits of stability (McIlroy and Maki 1993).



Figure 1.2 Demonstration (from left to right) of the hip, ankle and step strategies in the anterior direction.

The orientation of body segments with respect to gravity, the support surface, the visual environment and internal sets are crucial for postural control, the sensory components of which are discussed in section 1.3.1. As the environment changes individuals are required to reweight the sensory information (Horak 2006) according to the availability or accuracy of cues (Peterka and Black 1990). In a well lit environment healthy persons rely

primarily upon proprioception (70%), vestibular (20%) and visual (10%) cues for orientation to their environment (Peterka 2002). In conditions where cues are inaccurate or absent the central nervous system (CNS) reduces the weighting of this input and increases the weighting on remaining appropriate inputs. This provides more appropriate information regarding the orientation of the body in space in relation to task and environmental demands.

Age-related declines in constituent parts of the balance system including visual, vestibular and somatosensory function are well documented (Lord et al. 1991; Baloh et al. 2001; Baloh et al. 2003). The ability to integrate information appropriately, especially when presented with a secondary task is also affected by increasing age; with switching of attention between tasks worst in balance impaired older adults (Redfern et al. 2001; Woollacott and Shumway-Cook 2002; Siu et al. 2009). Reduction or alteration in function in any of the peripheral receptors, afferent fibres, effectors or central systems (both cognitive and integrative) whether by trauma, degeneration or disease processes can affect postural control (Sturnieks et al. 2008).

1.3.1 Sensory components of the balance system

1.3.1.1 Vestibular system

The role of the vestibular system is to contribute to gaze stabilisation, the sensation of orientation or movement and postural control. The vestibular apparatus are situated bilaterally within the inner ear and individually comprise of five pairs of motion detectors that are mirrored on either side of the head. The two otolith organs (utricle and saccule) detect horizontal and

vertical head accelerations and orientation of the head with respect to gravity. The three semicircular canals are positioned at 90° to each other, with each semicircular canal possessing an enlarged area (ampulla) where the sensory organ (crista) is located. Cupula deflection within the ampulla of the semicircular canals is caused by the movement of endolymph within it and provides information on rotational motion (angular acceleration) of the head (Figure 1.3).

The vestibular nuclei within the brainstem (superior, lateral, medial and inferior) receive their primary input from the vestibular portion of the VIII cranial nerve. Once vestibular information has reached the vestibular nuclei and the cerebellum, it is integrated with somatosensory and visual input. This information (vestibular, visual and somatosensory) is used to maintain postural stability by providing perceptions of the body position and orientation in space.

A series of vestibular reflexes exist that govern the control of eye movements (vestibular ocular reflex – VOR) and postural reactions (vestibulo-spinal and vestibulo-colic reflex). The VOR acts to maintain visual acuity during head motion by providing compensatory movements of the eyes in the opposing direction to head movement. Projections from the vestibular nuclei to the extraocular muscle nuclei allow for the control of eye movements which counteract head movements to enable gaze stabilisation. The VOR works in conjunction with optokinetic nystagmus (OKN) to keep the desired image stable on the retina (Gottlob 2000; Hain and Helminski 2007). This provides

context and acuity to vision when either objects or the head are moving. The vestibulo-spinal reflex (VSR) and vestibulo-colic reflex (VCR) allow for input from the vestibular organs to be used for postural orientation of the body in a gravity environment, serving to assist stabilise the trunk and head in space (Shupert and Horak 1996; Buchanan and Horak 2001). However, these reflexes only play a small role in postural control when both visual and somatosensory cues are present and accurate (Nashner et al. 1982; Maurer et al. 2000). The vestibular system therefore is a complex organ which provides information regarding orientation of the head to gravity, and drives a series of reflexes to maintain visual acuity and postural stability when the body and head are moving.

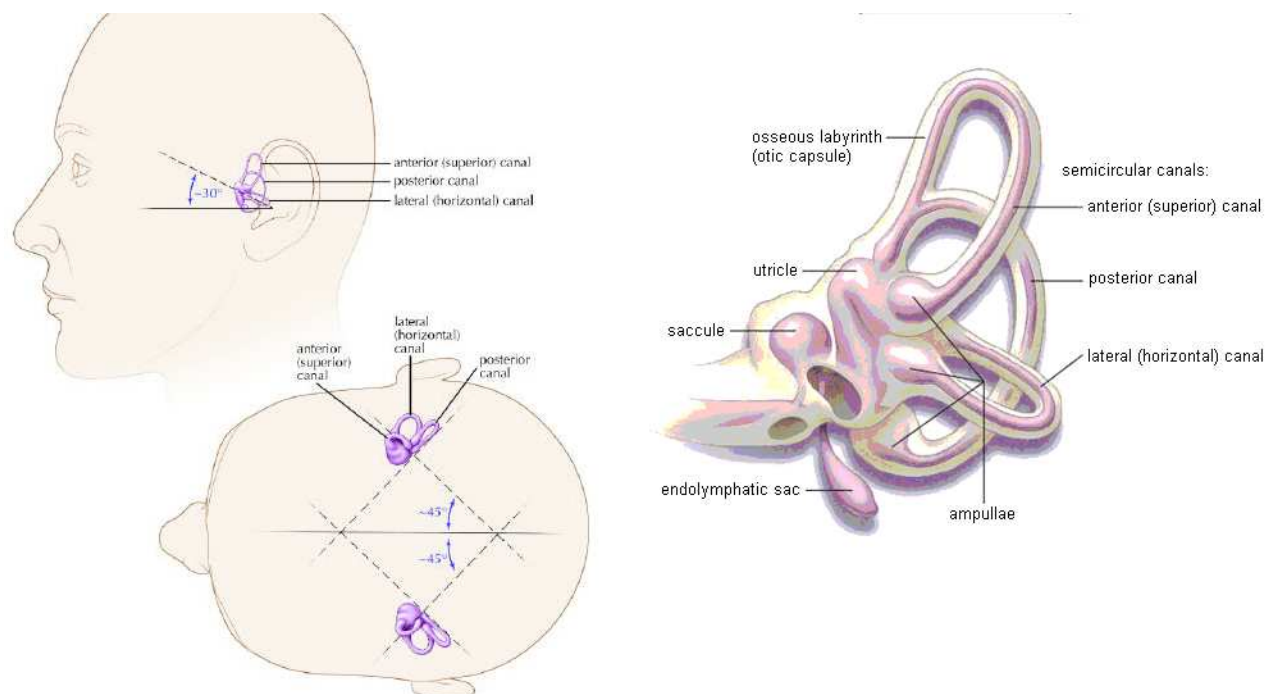


Figure 1.3: The organisation of the vestibular apparatus

(Adapted from (Parnes et al. 2003), used with permission © Copied under licence from the Canadian Medical Association and Access Copyright. Further reproduction prohibited.)

1.3.1.2 Visual system

Vision provides information relating to our position within the environment and where our environment is in relation to us. This therefore allows us to safely navigate, locate objects, predict the motion of objects, and provides cues regarding the perception of vertical. Regardless of a visual deficiency, older adults often report problems with their vision. Common complaints include blurring of distant objects, difficulties with simple visual tasks (such as reading and watching moving objects) and reduced ability to see in low light (Kosnik et al. 1988). Reduced contrast sensitivity under low light may put an individual at risk for falls due to trips, indeed reduced edge contrast sensitivity is a significant predictor of falls in older women (Lord et al. 1994).

When assessing postural sway in response to moving visual scenes (visual dependence) Borger et al (1999) reported that healthy older adults were more affected than younger adults by visual motion. Higher frequency movements of the visual surround significantly increased sway in older adults indicating increased reliance on visual information for postural stability (Borger et al. 1999). Fallers have also been identified as being more visually dependent compared to non-fallers in both seated and dynamic conditions (Lord and Webster 1990; Sundermier et al. 1996). These may have implications for postural stability in visually crowded environments or in situations of visuo-vestibular conflict.

Similar difficulties with visual tasks are described by a subset of individuals with peripheral vestibular dysfunction (PV). This phenomenon is known as

visual vertigo or space and motion discomfort (SMD) and can be demonstrated by large postural sway responses to optokinetic stimulation (OKS) (Jacob 1989; Bronstein 1995). It is thought that SMD emerges in individuals that have increased visual dependence and an inability to resolve visual and vestibulo-proprioceptive conflicting information (Guerraz et al. 2001). Although visual dependence has been identified in fallers, the incidence of specific SMD symptoms has not been assessed. Current rehabilitation programmes incorporating OKS and visual-vestibular conflict have shown significant improvements in SMD symptoms and postural stability both in healthy young subjects and patients with a peripheral vestibular disorder (Pavlou et al. 2004; Pavlou et al. 2011).

1.3.1.3 Somatosensory system

Somatosensory information from muscle spindles, golgi tendon organs, joint receptors and cutaneous mechanoreceptors provide information regarding the position of joints in space, joint torques and the interaction of the body with its support surface. Under normal lit conditions the somatosensory system provides 70% of the information required to maintain postural stability (Peterka 2002; Horak 2006). When somatosensory function is altered either by disease, aging or experimental manipulation increases in postural sway are observed (Lord et al. 1991; Kuo et al. 1998; Lord et al. 1999; Horak et al. 2002).

As adults age, changes occur in the function of sensory and integrative systems. Impairments in tactile and proprioceptive function are associated

with increased falls risk and greater impairments in gait (Lord et al. 1991; Lord et al. 1999; Baloh et al. 2003). Tactile sensitivity of the feet is significantly lower in multiple fallers compared to single- and non-fallers (Lord et al. 1994) and reduced function increases the risk for multiple falls by 2.3 times (Stalenhoef et al. 2002). Larger proprioceptive errors at the great toe, as measured by a self-initiated simultaneous position matching task are evident in multiple fallers (Lord et al. 1991; Lord and Ward 1994) and produces greater postural sway in older adults in quiet stance (Lord et al. 1991) and near tandem stance (Lord and Ward 1994). These decreases in postural stability with impaired toe proprioception increase the odds for recurrent falls by 5.7 times in older adults (Stalenhoef et al. 2002).

When somatosensory cues are disrupted, not only is there an increase in postural sway, but there is an alteration in selection of postural strategy used to maintain stability (Kuo et al. 1998). When disrupting foot proprioception by sway referencing the support surface there is a significant increase in the use of the hip strategy in healthy young adults rather than the ankle strategy. The authors attribute the increased use of the hip strategy due to the CNS misinterpreting sensory signals as corresponding to trunk or hip motion; of which the correct postural response would be hip motion. Interestingly, this may be observed in healthy older adults. Healthy older men use the hip rather than the ankle strategy when recovering from postural disturbances brought about by translation of the support surface (Okada et al. 2001). Similarly, older women have reduced ability to recover balance using the ankle strategy compared to younger adults when freed from a forward lean

position (Mackey and Robinovitch 2005). The authors did not assess foot proprioception or tactile sensitivity, and so the contribution of changes in strategy selection in these groups cannot be ascertained. However, if somatosensory function were impaired then this may provide an explanation for the increased use of the hip strategy.

1.3.2 Postural control in older adults

Postural control is considered a complex motor skill derived from the interaction of multiple sensorimotor processes and serves two main purposes. Firstly it serves to stabilise the position of the centre of gravity due to either self initiated or externally induced disturbances in stability. Secondly it maintains postural orientation in relation to the support surface, gravity, visual environment and internal references (Horak 2006). If any components of the postural control system have impaired function then postural control, and therefore stability, may be compromised.

Functional head movements such as turning left to right or looking up and down are essential for interacting with the environment around us for example, when looking for an object or when crossing a road. In older adults, voluntary head movements in yaw (turning to left and right) with eyes open or closed invoke higher amplitude and lower frequency sway in quiet standing (Koceja et al. 1999). The major contributing sensory input for quiet standing is thought to be the somatosensory system (Peterka 2002), but as head movements were above vestibular thresholds and vestibular testing was not

performed, pathology within this system cannot be excluded (Koceja et al. 1999). Impairments in vestibular function or integration of vestibular cues can lead to decreased stability when performing head turns both in static standing and when walking (Cohen and Kimball 2004).

The VCR is important for providing head stability in gait (Hirasaki et al. 1999) and therefore Impairments in function or integration of vestibular cues can lead to poor control of head stability when walking. Adults at high risk of falling exhibit reduced control head of accelerations when mobilising, especially when the support surface is irregular. A possible cause for this is impaired vestibular function, as the head is not effectively oriented to gravity as would be expected with functioning VCR. Poor head control may also compromise gaze stability due to increased demand on the VOR, increasing falls risk by reducing visual acuity (Menz et al. 2003) or due to unsteadiness brought about by impaired VOR activity (Baloh et al. 2001).

The use of postural control strategies has been shown to change with age; whereby older individuals adopt the hip rather than the ankle strategy (Figure 1.2) in response to perturbations of balance (Okada et al. 2001; Mackey and Robinovitch 2005). The authors consider a combination of reduced vestibular, somatosensory and musculo-skeletal functioning coupled with reduced central integrative and executive function as a possible cause for this. This is in agreement with the model for postural control put forward by Horak (2006). Functionally this alteration in postural control strategy may not be maladaptive, but an adaptation to improve efficiency of postural control

when there is an alteration in function of peripheral receptors or central integrators (Okada et al. 2001).

When standing with eyes closed or in conditions where visual and somatosensory cues are disturbed, fallers display impairments in postural control by exhibiting significantly greater sway than age matched non fallers (Murray et al. 2005; Buatois et al. 2006). This indicates a greater reliance on visual information (visual dependence) and reduced utilisation of vestibular cues for postural control. When confronted with conflicting visual information (a moving visual scene) healthy older adults exhibit greater postural and head sway than younger adults. When the support surface is sway referenced, sway is increased further as weighting of somatosensory cues are reduced and vision are increased (Borger et al. 1999; Sparto et al. 2006). However, no difference in head sway is observed between older adults with a unilateral vestibular disorder and healthy controls indicating an increased susceptibility to visual motion stimuli with age (Sparto et al. 2006).

1.3.3 Changes in the vestibular system with age

Non specific dizziness is prevalent in older adult populations. Cross sectional studies describe an overall self report of dizziness in 11% to 33% of community dwelling older adults (Tinetti et al. 2000; Jonsson et al. 2004; Stevens et al. 2008; Agrawal et al. 2009) and 61% for those attending medical outpatient clinics for unrelated problems (Oghalai et al. 2000). The occurrence of dizziness increases with advancing years, with up to 50% of older adults over the age of 85 reporting vertigo or dizziness (Jonsson et al.

2004). The multiple possible types of dizziness and underlying causes provide great difficulties to clinicians in diagnosing and providing appropriate interventions. Due to this high prevalence in older adults, dizziness has been postulated as a geriatric syndrome (Tinetti et al. 2000). Dizziness can be caused by any number of single or combination of medical problems including postural hypotension, drug interactions, psychiatric illness, cerebrovascular disease and vestibular dysfunction.

The prevalence of vestibular dysfunction in community dwelling older adults tested with the modified Romberg Balance Test is 49.4% in 60-69 year olds, 68.7% in 70-79 and 84.8% in 80+ (Agrawal et al. 2009). Although no studies exist comparing the modified Romberg test with standard clinical neuro-otology testing, this test utilises vestibular inputs when parallel visual and somatosensory inputs are absent. Falling when stood on the compliant surface with eyes closed indicates impaired use of vestibular sensory cues or impairments in sensory integration. In this large cross sectional study, falls were significantly associated with vestibular impairment and self report of dizziness; however differences between fallers and non-fallers were not reported. This study ties in with histo-pathological studies; whereby a reduction in both the number and volume of otoconia and sensory epithelia receptors have been noted in older adults (Merchant et al. 2000; Rauch 2001; Walther and Westhofen 2007). Longitudinal studies of healthy adults over the age of 75 also display clinical changes in vestibular function with age. Using rotation testing, Baloh et al demonstrated a clear deterioration in optokinetic and visual-vestibular responses, providing evidence of

progressive degeneration in function with advancing years (Baloh et al. 2001; Baloh et al. 2003). Although in these individuals no signs or symptoms of disequilibrium were noted, the number of falls reported significantly increased with advancing years (Baloh et al. 2003). This implicates reduced vestibular function in falls, although vertiginous symptoms were not reported, reduced function may have had a significant effect on postural stability. Impaired vestibular function may have a knock-on effect on physical function in frailer individuals due to the effects on dynamic visual acuity and postural orientation information. Baloh et al (2003) reported the highest number of falls in individuals with the lowest Tinetti scores, indicating poorer functional ability in tasks such as sit to stand, static standing and gait. However, scores were not significantly correlated with vestibular function. When mobilising it is important to be able to turn the head to scan the environment for hazards and to locate objects, thus utilising vestibular cues to maintain acuity. Head movements and scanning can be affected by reduced VOR function leading to sensations of instability and dizziness, which in turn may lead to falls (Baloh et al. 2001; Stevens et al. 2008). The Tinetti balance and gait test is performed on a level surface with eyes open and does not require any head movements when performing. Therefore visual and somatosensory systems are predominantly used for postural stability, therefore impairments in vestibular function and subsequent instabilities may not be observed when using the Tinetti test.

Although vestibular function tends to decline in sedentary older adults, it has been demonstrated that practising physical activities can serve as protective

or regenerative to vestibular function. Individuals that regularly practise physical activity have improved gaze control, greater efficiency of postural reflexes and greater vestibular symmetry than age matched individuals that do not (Gauchard et al. 2003; Gauchard et al. 2004). If taken up in older age the sensitivity of the vestibular apparatus can be improved in older adults, indicating that physical activity may have a protective effect on vestibular function (Gauchard et al. 2004). Similarly vestibular rehabilitation is just as effective in older adults as it is in younger adults, with no significant difference in changes in gait, balance confidence, reported symptoms or falls (Whitney et al. 2002).

1.3.4 Vestibular function and falls in older adults

Of older adults that present to accident and emergency following a fall, 41% reported experiencing vertiginous symptoms and 80% reported symptoms of vestibular system impairment on the Vertigo Symptom Scale. Many participants reported feelings of giddiness and unsteadiness which are typical subjective descriptors of vestibular system dysfunction used by older adults (Pothula et al. 2004). Older adults perform worse when standing on compliant surfaces with eyes closed, indicating poor utilisation of vestibular cues (Agrawal et al. 2009), with fallers performing significantly worse than non fallers (Murray et al. 2005). Similarly, 73% of older adults referred for multifactorial falls risk assessment due to falls, or at high risk for falls, have impaired vestibular function on clinical investigation. Of these, 17% had central vestibular system impairment and 56% had a lesion of the peripheral vestibular system (Jacobson et al. 2008). These impairments may lead to

asymmetric or absent vestibular function affecting the VOR, VSR and VCR, which in turn may affect dynamic visual acuity, orientation, righting reactions and gait.

Asymmetric or reduced vestibular function is associated with fractures of both the wrist and hip (Kristinsdottir et al. 2000; Kristinsdottir et al. 2001; Zur 2006). Zur et al (2006) reported that individuals with a hip fracture were 5 times and 3 times more likely to have impaired VOR and a positive head thrust respectively compared to age-matched healthy controls. Kristinsdottir et al (2001) reported 76% of older adults treated in the emergency room for wrist fractures had head shake nystagmus, indicating vestibular asymmetry. This proportion was significantly greater than was evident in a healthy older adult population. Thus this high proportion of vestibular dysfunction in falls warrants further investigation.

Benign paroxysmal positional vertigo (BPPV) is the most common vestibular disorder and is brought about by displacement of the otoconia into the semi circular canals, most commonly affecting the posterior canal (Hilton and Pinder 2004; Uneri and Polat 2008) and increases in prevalence with age. BPPV has a typical presentation of short latency rotatory vertigo, nystagmus and /or nausea brought about by head movements or postural change such as rolling over in bed (Lawson et al. 2008; Gananca et al. 2010). BPPV accounts for approximately 40% of all dizziness in older adults referred to neurotology clinics for balance assessment (Uneri and Polat 2008). However, BPPV commonly presents with atypical symptoms in older adults;

such as postural dizziness, sudden intense unsteadiness and falls which are not brought about by typical provoking positions (Lawson and Bamiou 2005; von Brevern et al. 2007). Older adults with BPPV are significantly more likely to have fallen in the previous 3 months compared to those without BPPV (Oghalai et al. 2000) and are significantly more at risk for falls than individuals with any other form of dizziness (Lawson et al. 2008).

As older adults: i) tend not to report typical rotatory symptoms even when vestibular pathology is present, ii) have a less specific presentation (combined with multiple co-morbidities) and iii) report unsteadiness and fall, they are more likely to be referred into a falls service for assessment and rehabilitation rather than to a specialist neuro-otology / ENT service (Lawson et al. 2005). Therefore assessing for vestibular function in fallers may be advisable, and provide greater insight into the management of this complex group of patients.

1.4 Measuring falls risk in older adults

Creating a measure that has the sensitivity to predict future falls in older adults has been the goal of many researchers over the past 20 years. A variety of different assessments exists, both physical and self-report which are commonly used in clinical practise to predict the risk for future falls. Physical measures broadly dichotomise into either static or dynamic measures. Static measures assess the control of static standing balance whereas dynamic measures require the control of posture through movements such as reaching, performing transfers or gait. This section will

describe some measures commonly used in clinical falls and balance clinics to determine falls risk.

1.4.1 Static Measures

The PPA is a measure to determine falls risk by standardised physiological measures which are independent predictors of future falls irrespective of disease conditions. The test consists of four seated tests (vision, reaction time, proprioception and muscle strength) and one static postural sway measure. Raw data for each test is converted to Z scores derived from data collected from age-matched Australian community dwelling older adults (Lord et al. 2003). The PPA computes a standardised fall risk score derived from a weighted combination of the Z scores, with 75% predictive accuracy for future falls (Lord et al. 2002). Falls risk of below 0 / 0-1 / 1-2 / 2+ relate to Low / Mild / Moderate / Marked risk respectively (Lord et al. 2002). The individual Z scores allow for specific deficiencies to be identified for targeted treatment programmes (e.g. poor quadriceps strength) (Lord et al. 2003). However, interventions designed to improve scores in individual measures identified as abnormal do not reduce falls rate in older adults, although PPA falls risk is improved (Lord et al. 2005).

The sensory organisation test assesses a person's ability to maintain postural stability under different sensory situations. Individuals stand facing a screen which fills the visual field on a force plate to measure sway in the anterior-posterior and medio-lateral directions. Six tests (each repeated three times) are performed which include standing with eyes open, eyes closed

and eyes open with the screen sway referenced. Sway referencing the screen provides erroneous visual feedback, therefore providing sensory conflict between somatosensory, vestibular and visual systems. The same three tests are repeated but with the force plate sway referenced, therefore providing errant somatosensory information also. Scores for each test are provided (normalised to age) and a composite equilibrium score is determined from the combination of these. Equilibrium scores <70% are considered abnormal (Neurocom 1999) and a cut off of 38% (53% sensitivity and 87% specificity) is predictive for multiple falls in community dwelling adults with balance disorders (Whitney et al. 2006). Falls in condition 6 of the SOT (visuo-vestibular conflict in the absence of somatosensory information), is the greatest SOT predictor of multiple falls in older adults. With those that fall in this condition being 3.6 times more likely to experience multiple falls than those that do not (Buatois et al. 2006).

Although static measures to assess falls risk can predict future falls with moderate sensitivity, they have little ecological validity with real world situations. Postural control is a dynamic task that requires movement through, and interaction with the environment, and therefore dynamic tasks may be more appropriate for assessing falls risk.

1.4.2 Dynamic Measures

A large amount of activities of daily living can require dynamic postural control such as dressing, performing household chores and mobilising (whether indoor or outdoor). The majority of outdoor falls occurs when

mobilising (Li et al. 2006) so it would be prudent for an assessment of falls risk to incorporate this into the test. One of the simplest dynamic tests is the Timed up and Go test (TUG) (Podsiadlo and Richardson 1991). This requires a person to raise from a chair, walk three metres at their self selected speed, turn around, walk back to their chair and sit back down again. There are a number of cut off scores for predicting falls and falls risk using the TUG, ranging from ≥ 11 seconds (Podsiadlo and Richardson 1991) to 13.5 seconds with 80% sensitivity and 100 specificity (Shumway-Cook et al. 2000). Scores of ≥ 15 seconds predicts high PPA falls risk with 81% sensitivity and 39% specificity (Whitney et al. 2005). Due to its ease to perform, lack of need for equipment and predictive accuracy for falls in older adults the TUG is commonly used as a screening tool for older adults considered being at risk for falling. Although the TUG assesses gait speed, which is functionally important, it does not assess the quality of performance, ability to modify gait to task demands or ability to perform other functional dynamic balance tasks.

The Berg Balance Scale (Berg et al. 1992) (BBS) is commonly used in both inpatient and community settings as it requires little space and equipment to perform and begins to assess functional dynamic balance ability. The BBS has 14 items rating a person's ability to stand, reach forward, transfer, look over shoulders and turn 360 degrees measured on a 4 point scale ranging from 0 (unable) to 4 (normal). A cut off score of 45/56 is normally used to predict falls. However, a prospective study identified sensitivity of 42% and specificity of 87% for multiple falls using this cut off (Muir et al. 2008) questioning the appropriateness of dichotomising the score. The authors

recommend that likelihood ratios across score intervals should be used to identify risk instead. A criticism of the BBS is that it does not contain a gait component, however it does correlate moderately well with complex gait measures such as the dynamic gait index (0.67) (Shumway-Cook et al. 1997).

The Tinetti performance oriented mobility assessment (POMA) (Tinetti 1986) comprises a 9 item balance scale and an 8 item gait scale with scores of 18/28 or below identifying risk for falls. The balance scale incorporates sit-to-stand, static and perturbed standing balance and ability to turn 360 degrees and the gait measure assesses step height, step symmetry and base of support. Positively, the POMA does have a gait assessment, but it does not assess a person's ability to mobilise in more complex situations such as stepping over objects, turning the head and using stairs, which have more functional implications.

The dynamic gait index (Shumway-Cook A and Woollacott M 1995) was designed to provide a more complex ambulatory test in which an individual had to modify gait to task demands. It consists of 8 items including; change in gait speed, walking with head movements, stepping over an obstacle and pivot turn. Scores of 19 or below are predictive of falls in older adults with 59% sensitivity and 64% specificity (Shumway-Cook et al. 1997). Similarly the DGI is able to predict falls in individuals with vestibular disorders with a cut off score of 18 or below with 70% sensitivity and 51% specificity (Whitney et al. 2004). However, in more able subjects with vestibular disorders the

DGI has been shown to have a ceiling effect thus placing some doubt in its clinical effectiveness in very mobile older adults (Wrisley et al. 2003). Due to this ceiling effect the DGI was modified to form the 10 item functional gait assessment (FGA). The stepping around obstacles item was removed and walking with narrow base of support, eyes closed and walking backwards were added (Wrisley et al. 2004). Items are scored on a 4 point ordinal scale (0 = "Severe impairment", 4 = "Normal") with a cut off of 22 points predictive of falls in older adults with a sensitivity of 100% and specificity of 72% (Wrisley and Kumar 2010). Although only one study has been performed to date to validate the FGA in fallers, it has been shown to correlate well with established measures of falls risk such as the Berg Balance Scale and the Timed Up and Go (Wrisley and Kumar 2010).

1.5 The Rehabilitation of Older Adult Fallers

1.5.1 Current Practice in Falls Rehabilitation

The British Geriatric Society (BGS) recommend multi-factorial interventions for the prevention of falls in older adults. Recommendations for intervention include gait training, exercise incorporating balance training, home modification and treatment of medical issues (American Geriatrics Society and British Geriatrics Society 2010). Many exercise programmes have been developed to reduce falls rates in older adults, with varying effects. At present, no single programme is recommended for use above others (NICE 2004). Modifying known falls risk factors can significantly reduce the rate of falls over one year compared to individuals receiving no intervention or usual

care (Tinetti et al. 1994; Close et al. 1999). However, a number of more recent studies contradict this, stating no effect of multifactorial interventions on falls rate in older adults (Elley et al. 2008; Hendriks et al. 2008; Salminen et al. 2009). Adherence to the interventions provided was poor in all studies and therefore non-significant results are not unexpected. In Tinetti et al's (1994) study; where rate of falls was significantly reduced, the rate of injurious falls experienced by participants was not affected by the multifactorial intervention. Gates et al (2008) performed a meta analysis of 19 studies, concluding that multifactorial interventions did not significantly reduce falls rate or injurious falls in older adults and that the overall effect of these interventions is limited. Although multifactorial interventions are recommended by the AGS/ BGS, a reduced effect of these interventions has been identified. This may in part be due to the assessment itself, with factors associated with elevated falls risk not routinely included in the multifactorial falls screening. Such factors include: vestibular pathology (Kristinsdottir et al. 2000; Kristinsdottir et al. 2001; Jacobson et al. 2008), dual tasking ability (Toulotte et al. 2006; Neider et al. 2011) and dynamic balance. Therefore although the AGS / BGS recommend exercise interventions to reduce falls risk in older adults, the nature of the assessment and targeted rehabilitation protocols derived from these may need to be modified. This may improve outcomes in fallers, especially in light of the reduced dual task ability, sensory integration and vestibular function in this group.

1.5.1.1 Strengthening based programmes to reduce falls

Both seated and weight-bearing strengthening programmes reduce PPA falls risk compared to social visits alone. Seated exercises provided a progressive programme targeting all major muscle groups of the lower limbs, whilst weight-bearing exercises included exercises to improve all major lower limb muscle groups and postural exercises including weight shifts, tandem standing and gait. Weight-bearing exercises provide additional improvements in co-ordinated stability, maximal balance range and postural sway (Vogler et al. 2009). As postural exercises were also provided to the weight bearing exercise group, improvements in postural tasks may be attributed to supplementary balance exercises and not strengthening. Also, only PPA falls risk and static balance measures (with eyes open) improved, with no change in ability to stand on foam with eyes closed or normal gait noted, indicating a lack of functional effect for ambulatory adults. Resistance and agility training also reduce PPA falls risk, with stretching interventions having no significant impact on falls risk (Liu-Ambrose et al. 2004). Beneficial effects of both training protocols were observed in reduced postural sway. This would have been expected from the agility programme which included dynamic balance, leaning balance and obstacle courses; thus improving awareness of and position of centre of gravity. The strength training protocol involved using free weights when performing lunges, squats and bicep/tricep curls. Squatting, lunging and raising weights above the head requires considerable postural control and anticipatory control to maintain stability; as the centre of gravity is being perturbed by an external load. Strength did not significantly increase in either group and therefore the effect of controlling an external load to train

stability may have been the mechanism for improvement. Once again, although improvements in PPA falls risk were noted, improvements in gait were not noted for any group.

This lack of effect on improving gait using programmes with little dynamic balance training can also be seen in falls rate when coupling rehabilitation to specific PPA impairments (Lord et al. 2005). This 12 month programme included twice weekly exercise sessions based on individual PPA deficits, correcting visual impairments and counselling. This programme significantly reduced PPA falls risk; however no effect on falls rate was noted.

Programmes which focus primarily on strengthening reduce PPA falls risk but do not significantly impact upon other functional mobility measures such as the community balance and mobility scale (CB&M) (Liu-Ambrose et al. 2004), physical performance and mobility examination (PPME) scores, gait velocity (Vogler et al. 2009) or falls rate (Lord et al. 2005; Vogler et al. 2009). Targeting the musculature of the lower limbs, especially the quadriceps has been identified as important in improving gait speed, as quadriceps strength is the strongest predictor of gait speed (Bohannon 1997; Callisaya et al. 2009). Lack of effect in gait measures and falls rate highlights the need for alternate rehabilitation strategies, which may incorporate greater emphasis on balance training to improve gait measures and reduce falls rate in older adults.

1.5.1.2 Combining balance and strength training to reduce falls rate

Community dwelling older adults that receive group interventions including strengthening and balance exercises have a significant decrease in falls rate compared to individuals that receive vision or home modification alone (Day et al. 2002). The OTAGO exercise programme (OEP); a commonly used falls rehabilitation programme consists of progressive muscle strengthening and balance retraining exercises combined with a walking programme. Strengthening exercises included in the OEP use either body weight or ankle weights and target the lower limb muscles around the ankle knee and hip. The balance and gait exercises typically require the individual to stand or mobilise with reduced base of support with or without support (e.g. tandem stance, single leg stand, walking on toes, heel-toe walk). Numerous studies have shown reductions in falls rate between 30% and 46% (Campbell et al. 1999; Robertson et al. 2001; Robertson et al. 2001) and a meta-analysis of all data revealed average reductions in falls rate of 35%. Best results are noted in frailer females over the age of 80 (Robertson et al. 2002). If fallers continue to practise exercises independently, the OEP significantly reduces the occurrence of falls in community dwelling older adults at one and two years post course completion (Campbell et al. 1999; Robertson et al. 2001). The OEP improves static balance function as measured by the 4 test balance scale (Campbell et al. 1997; Robertson et al. 2002). However, gait speed, functional reach and stair climbing did not improve, demonstrating a lack of effect of the OEP on dynamic balance (Campbell et al. 1997; Robertson et al. 2002; Liu-Ambrose et al. 2008). Dynamic balance is crucial for maintaining postural stability when performing everyday tasks such as

ambulation, housework and shopping. The exercises within the OEP focus primarily on improving peripheral musculature and may increase the use of the somatosensory or visual systems. This is because all exercises are performed on level floor with eyes open with the individual instructed to look directly ahead. This intervention programme does not provide sufficient targeted exercises to improve sensory integration or reweighting. Techniques such as altering the support surface or removing visual fixation may assist with sensory integration and reweighting. Also, the OEP does not target the utilisation of vestibular cues for balance by integrating vestibular exercises. Both sensory reweighting and vestibular exercises may have a supplementary beneficial effect on sensory integration, postural stability and gait. However, at present there is a lack of evidence to support supplementing the OEP with other exercises designed to promote sensory integration, stability and gait.

Tai Chi is a martial art which requires slow, controlled and co-ordinated movement of the limbs, trunk and head, to produce movement of the centre of gravity through its base of support and incorporates single leg stance. Due to this training in co-ordination and control, the benefits for balance function can be imagined, and as such Tai Chi has been identified as a possible adjunct to traditional falls rehabilitation. Tai Chi can reduce the risk for multiple falls significantly compared to individuals not undertaking Tai Chi. Time to first fall is increased by 30% and improvements in co-ordinated stability score and postural sway are noted (Voukelatos et al. 2007). When comparing Tai Chi against stretching, Li et al (2005) noted that the Tai Chi

group experienced significantly fewer falls, lower falls risk and greater functional balance as measured by the DGI which persisted after 12 months. Although this study shows promising effects for gait, neither group were at risk for falls at baseline, so the effect on Tai Chi as a rehabilitative programme for fallers cannot be determined from this study. Combining Tai Chi with strength and balance training for individuals with risk factor for falls (Barnett et al. 2003) can decrease falls rate by up to 40% compared to controls provided only with information on falls reduction. However, no effect on gait speed was noted and no formal assessment of gait ability was taken. The efficacy of Tai Chi in falls rehabilitation cannot at present be determined, as although it has been demonstrated to reduce falls risk and rate in community dwelling older adults, its efficacy in a falling population has not been determined.

1.5.2 Novel Approaches to therapy

1.5.2.1 Vestibular rehabilitation therapy (VRT)

There is a greater body of evidence emerging for the targeted rehabilitation of balance dysfunction following vestibular insults than for balance rehabilitation of older adult fallers. Techniques to promote sensory integration and reweighting and central adaptation to alterations in peripheral function in patients with vestibular disorders come under the umbrella term of vestibular rehabilitation therapy (VRT). Peripheral and to a lesser extent central vestibular symptoms respond to VRT with numerous studies showing significant improvements in balance, gait, symptoms and associated

psychological factors (Patten et al. 2003; Badke et al. 2004; Cohen and Kimball 2004; Pavlou et al. 2004). Also, specific manoeuvres which induce the return of otolithic debris from the posterior canal back into the utricle are effective in the treatment of BPPV (Herdman 1997).

When providing VRT, a customised programme has a significantly greater effect than a generic treatment protocol in improving symptoms, static and dynamic postural control (Shepard and Telian 1995). Exercise based VRT serves to promote compensation, adaptation and substitution within the central nervous system. Standard physiotherapeutic interventions i.e. postural retraining, conditioning and occupational interventions are also provided to improve function (Badke et al. 2004; Pavlou et al. 2004; Hillier and Hollohan 2007). Exercise regimes may vary depending on the presenting complaint of the patient. Gaze stability exercises are provided to reduce dizziness, standing and walking exercises provided to improve postural control and a combination of the two if presenting with both (Whitney and Sparto 2011). To promote sensory adaptation the support surface, base of support and visual information may be modified.

Regular exposure to optokinetic stimulation over a short duration (5 days) can modify postural responses to improve postural stability when exposed to a rotating disc. It can also modify perceptual responses by improving subjective visual vertical as measured by the rod and disc test (Pavlou et al. 2011). However the long term carryover of exposure has not been assessed. Customised VRT, when combined with visual motion stimuli have a greater

therapeutic effect than customised exercise alone, providing a significant reduction in symptoms of space and motion discomfort (Pavlou et al. 2004). Although this randomised controlled trial provided strong evidence for the use of optokinetic stimulation and demonstrated improvements in postural control, no formal assessment of gait was performed to provide greater insight into the effects on dynamic postural control.

By promoting compensation, adaptation and substitution within the central nervous system, VRT has been shown to improve dynamic visual acuity, postural stability and gait and reduces falls in patients with vestibular disorders. By comparing a 4 week programme of active vestibular with neutral exercises, the role of vestibular adaptation in improving dynamic visual acuity (DVA) in patients with vestibular deficits has been identified (Herdman et al. 2003). Those that underwent VRT had significantly greater improvements in DVA; indicating improved VOR function. Interestingly age did not affect recovery indicating that VRT is beneficial in older and younger adults alike. Similarly a lack of effect of age on VRT outcomes has been reported in a number retrospective chart reviews of patients with vestibular dysfunction (Whitney et al. 2002; Hall et al. 2004). VRT significantly improves dynamic gait index scores in older and younger groups alike, thus reducing falls risk, although a greater proportion of older adults may remain at risk for falls following VRT (Hall et al. 2004). Not only does VRT improve physical symptoms, it reduces vertigo intensity, and improves ability to perform ADL's and mood in patients with vestibular disorders (Cohen and Kimball 2003; Cohen and Kimball 2004; Pavlou et al. 2004). Gaze stability exercises can

also reduce perceived dizziness in older adults with no known vestibular disorder, indicating a possible use for VRT in the treatment of dizziness (Hall et al. 2010). Many of these factors may have a major effect on an individual's quality of life and level of independence.

1.5.2.2 Multi-Sensory Rehabilitation of older adults

There is a growing body of literature implicating impaired sensory integration and vestibular dysfunction in falls in older adults (see section 1.3.4). Hu et al (1994) described a rationale for providing multisensory rehabilitation, which was to improve the selection of appropriate sensory modalities and increase the speed of sensory reweighting in healthy older adults (Hu and Woollacott 1994; Hu and Woollacott 1994). These studies utilised a static postural training task and modified sensory inputs by either the presence or absence of: 1) a foam cushion (somatosensory), 2) neck extension (vestibular) or 3) eyes closed (visual). Each condition was practised independently and in combination to provide multiple opportunities for sensory reweighting. The authors report that after training, static balance was significantly improved in conditions of sensory conflict and when standing on one leg. However, although improvements in static postural control show promising results, no measures of dynamic control or gait were performed which would identify functional carry-over of these interventions. The FaME programme (Skelton and Dinan 1999); introduces walking on different surfaces, head and eye movements, and exercises from the Cawthorne-Cooksey regime into falls rehabilitation. This programme significantly reduces fall rates in older women fallers (Skelton et al. 2005) by up to 30% compared to control groups

provided with stretches. Although this programme shows positive results, the length of intervention (2x weekly for 36 weeks) and therefore cost to NHS providers to implement is great. The rate of introduction of multisensory exercises is slow, with the first introduced at week 12. Support surface is not altered in walking until week 24 and vestibular exercises are performed for the last 4 weeks of the programme only. This programme may be made more efficient by integrating multi-sensory training at onset to improve postural stability and gait by providing greater opportunity for sensory integration, reweighting and adaptation.

More recently, studies introducing multi-sensory balance training early on in the programme have begun to be described for older adults at risk for falls (Beling and Roller 2009; Williams et al. 2010). However the rationale for providing these exercises are not always clearly described. The study by Beling and Roller (2009) demonstrated significant improvements on the TUG, composite Sensory Organisation Test score and reduced falls rate in older adult fallers. However, this study had relatively small numbers (n=23) with no measure of effect size, did not provide customised rehabilitation and the specific benefit of practicing vestibular exercises was not assessed. In the study by Williams et al (2010) older adults with arthritis displayed significant improvements in falls risk, activity profiles, fear of falling, functional reach, and step width after completing a multisensory training programme. The programme consisted of a combined OTAGO and advanced balance rehabilitation programme incorporating vestibular exercises. Prior to commencing the study thirty five percent of the study

subjects had not fallen and twenty percent had only fallen once in the previous year. The analysis of this study did not control for falls history and did not collect prospective falls data. Therefore bias due to possible greater improvements in non-faller groups cannot be ruled out and the effect of the intervention on falls rate cannot be ascertained. Both studies identify that multisensory training may have positive effects, but as both are simple comparisons without controls performing alternative exercises, the effect of the intervention compared to traditional and established therapies cannot be determined.

A recent RCT (Yang et al. 2012) compared a 6 month multisensory training programme to normal activity plus education regarding falls in older adults with mild balance dysfunction. The active intervention group had greater functional reach ability and reduced step width compared to controls at study completion indicating greater postural control in the intervention group. However falls efficacy and gait speed were not significantly different between groups, although both were within normal ranges at study outset, so improvements may not have been expected. Also, specific measures to detect vestibular symptoms (and improvements in them) were not utilised. Therefore, the role of multi-sensory training in reducing falls risk, rate and improving subjective symptoms of balance dysfunction have not been identified in the current literature.

Exercises to address vestibular function in older adult fallers are beginning to be integrated into balance rehabilitation programmes for older adults.

However, few studies at present are randomised controlled trials, lack long term follow up and many only provide pre-post intervention comparisons. No studies to date have specifically assessed whether multi-sensory falls rehabilitation contributes to a reduction of falls risk or an improvement in balance symptoms in older adult fallers.

1.6 Aims of thesis

The following section will provide a brief synopsis of the purpose of each study included in this thesis. The first chapter (Chapter 2) investigates five physiological measures independently associated with falls in older adults (Lord et al. 1992; Lord et al. 2003), and how their contribution to falls risk and variability changes in different age groups.

A reduced ability to perform simultaneous tasks has been identified in older adults, with greater impairments observed in fallers compared to non-fallers (discussed in 1.2.2.8). Chapter 3 describes a novel multi-task test to investigate the ability of older and younger adults to process two spatial tasks delivered by separate sensory modalities, and the effect this may have on volitional step responses. This was intended to provide a complex test which may begin to identify changes in prioritisation between postural and non-postural tasks if the individual is suitably challenged.

There is a body of evidence to suggest that vestibular function (or the ability to utilise vestibular cues) decreases with age and that vestibular dysfunction

may be associated with falls in older adults (discussed in sections 1.3.3 and 1.3.4). Chapter 4 attempts to identify the prevalence of vestibular dysfunction in both community dwelling ambulatory fallers that have no suspected vestibular pathology and healthy older adults. No studies to date have compared age matched fallers and healthy adults in clinical tests of vestibular function. Therefore a greater understanding of the role of vestibular dysfunction in falls may provide important information for clinicians and for those designing and providing rehabilitation protocols. Fallers were also compared with both age-matched healthy individuals and individuals with known peripheral vestibular disorders across a range of physical and subjective measures to determine the effects of falls and vestibular pathology on function compared to healthy adults.

Current falls rehabilitation programmes such as the Otago can reduce falls on average by 35% (Robertson et al. 2002) (discussed in section 1.5.1.2). However, the Otago does not contain any multisensory training component. Evidence suggests that multisensory programmes can reduce falls risk and reduce falls rate in older adults (see section 1.5.2.2), however their effectiveness has not been demonstrated in comparison to another falls programme. Chapter 5 aimed to investigate the beneficial effects of providing multisensory rehabilitation provided in supplement to the Otago on falls risk, complex gait and subjective reports of vestibular symptoms and balance confidence.

Chapter 2. The Physiological Profile Assessment: Clinical validity of the postural sway measure and comparison of impairments by age.

2.1 Abstract

Background: The physiological profile assessment (PPA) assesses falls risk in older adults by measuring impairments most associated with multiple falls. To date no study has investigated the change in PPA impairment profile with age.

Objective: To describe impairment profiles, by age and ability to complete the postural sway measure, of older adults fallers.

Participants: 885 older adults referred to multi-disciplinary falls clinics located within two inner London boroughs (UK).

Methods: Anonymised data was extracted from the PPA falls risk database. For comparisons, data was grouped by gender, age, and ability to complete the postural sway test.

Results: There were significant differences between all age groups in PPA falls risk, edge contrast sensitivity, quadriceps strength, postural sway and reported falls within the previous year ($p < 0.01$). The oldest age group (90+) had the highest PPA falls risk ($p < 0.01$) yet reported significantly less falls than the youngest age group (60-69; $p < 0.05$). There was significant variability in test results, with younger age groups displaying greater variability across PPA measures, and older age groups displaying more consistency ($p < 0.05$). 15.1% ($n=134$) of patients that were able to perform the postural sway measure received a higher risk score for this test than those unable to complete the task.

Conclusions: Greater variability in younger age groups indicates that specific impairments may provide the cause of falls, whereas widespread global reduction in function and frailty may provide the cause for falls in the older age groups. The postural sway scoring does not reflect ability to perform the test.

2.2 Introduction

Falls are a major cause of disability and the leading cause of injury related death in people over 75 in the UK. In the UK approximately one third of people over 50 have at least one fall each year, with rates higher in women than in men and increasing rates with advancing years (O'Neill et al. 1995; Fleming et al. 2008).

It is widely accepted that there are incremental age-related decreases in many physiological systems including peripheral sensation, vision, strength and vestibular function which may have a detrimental effect on balance function (Lord et al. 1991; Lord and Ward 1994; Kuo et al. 1998). Many falls risk assessment tools examine functional ability, which is generally limited by age related decreases in function which in turn may lead to impaired balance. The Short Form Physiological Profile Assessment (PPA) (Lord et al. 2003) was developed to provide an affordable and low-tech battery of tests to assess falls risk by identifying impairments in key physiological measurements irrespective of health conditions. These tests act individually as predictors for multiple falls in older adults, and, in combination have a reported ability to identify 75% of multiple fallers in prospective studies (Lord et al. 1991; Lord et al. 1994; Lord et al. 1994). The test measures are: edge contrast sensitivity, measured using the Melbourne Edge Test (MET) which requires identifying the orientation of a line separating two semi-circles of varying contrast, hand reaction time (Rthand) using a button press paradigm, knee joint proprioception (Prop) using a joint matching test, maximal isometric quadriceps strength (Quad) and postural sway when stood on foam

with eyes open (please see Figure 2.1 for diagrammatic representation of tests) . These scores are standardised for age and sex and combined to compute a falls risk score, of which positive values indicate a higher risk for falls (Lord et al. 2003). Most test measures have acceptable reliability (ICC's of 0.5+), however the proprioception test has low reliability (Lord et al. 1991). The developmental work for this tool has published results regarding differences between fallers and non fallers, the relative contributions of each test to risk and PPA falls risk in different populations of patients, but no data regarding the variations in impairment profile which may occur with age has been published (Lord et al. 1994; Lord et al. 2003; Lorbach et al. 2007; Szabo et al. 2008). These impairment profiles may be clinically important, as many UK falls clinics provide standardised strength and balance training, as recommended by the National Institute for Clinical Excellence (NICE 2004) in a structured group rehabilitation programme to fallers, irrespective of age. The aim of this study is therefore to investigate PPA impairment profiles by age group.

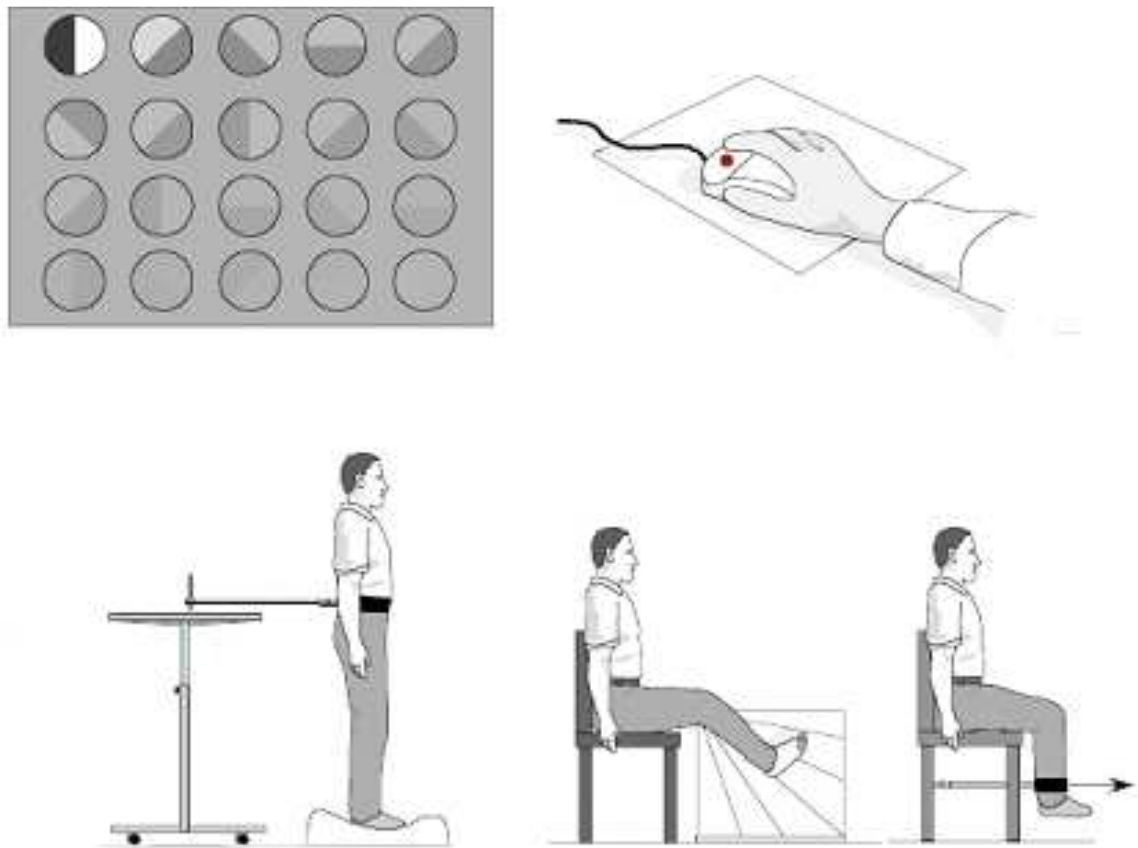


Figure 2.1 Diagrammatic representations of component tests of the PPA, clockwise from top left: Melbourne Edge Test, Hand Reaction Time, Maximal Isometric Quadriceps Strength, Knee Joint Proprioception, Postural Sway (Used with permission).

2.3 Methods

Anonymised retrospective data from the PPA Falls Risk calculator database (www.powmri.edu.au/fbrg) entered from three of the four clinic sites of the Southwark and Lambeth Integrated Care Pathway for Fallers (*SLIPS*) were collated (one site omitted due to difficulties accessing data). Inclusion criteria

were (i) age 60 years or older; (ii) initial assessment PPA only, not follow-up, and (iii) complete datasets. Out of 1170 entries made during the time window inspected, 885 fulfilled these criteria (75.6%). Of the excluded cases 64% were duplicate entries, 14% were incorrectly entered onto the database, 13% were follow-ups and 9% were < 60 years of age.

Within SLIPS, the PPA is administered by physiotherapy staff in compliment to a comprehensive medical assessment of visual acuity, cardiac function, tests for focal neurology and medication review. The PPA is administered in patients with a Timed Up and Go (TUAG) time of ≥ 15 seconds or an inability to perform the TUAG, as was previously reported to be predictive of high PPA falls risk in SLIPs patients (Whitney et al. 2005) and therefore in need of more targeted therapeutic interventions.

Raw data for each component test from the PPA is entered onto the web-based PPA falls risk calculator database alongside age, gender and the number of self-reported falls within the past 12 months.

2.3.1 Statistical analysis

Extracted data on self-reported falls rate, raw individual measure results and the (weighted) computed total PPA falls risk score were entered into SPSS version 16 (SPSS Inc.) for analysis. Descriptive data for age groups (median and range) of the total sample were determined. Differences in gender composition were assessed using the Chi Squared test. Data was not normally distributed, therefore non-parametric statistics were utilised.

Due to the high proportion of subjects (43.3%) unable to perform the postural sway test, thus receiving a default score of two standard deviations from the norm, data was stratified and re-analysed as those who a) completed the test with a sway area under 2500mm^2 (less than 2 S.D.), b) completed the test in greater than 2500mm^2 (greater than 2 S.D.) and c) were unable to perform the test. Kruskal-Wallis tests were used to assess for differences between groups based on age and ability to complete the postural sway test. Post-hoc analysis was performed using multiple Mann-Whitney tests with Bonferroni correction, with an alpha value of $p < 0.05$ for all comparisons (Field 2005). Higher scores in MET and Quadriceps strength, and low scores in proprioception, reaction time, sway, falls risk and reported falls indicate less impairment.

To compare variability in results between age groups and those able to complete the postural sway test, firstly the raw data was standardised by converting each variable to a Z score based on the whole test population. The standard deviation of the five PPA Z score measures was then computed for each individual to give a measure of variability across all measures. The Kruskal-Wallis test was used to assess variability in the mean ranks of standard deviations between all age groups

2.4 Results

2.4.1 Gender comparisons

At all sites, more women than men attended the clinics: total 639 females (72.2%, $p<0.01$), site A, $n=411$ [71.3%], site B, $n=185$, [76.8%], site C, $n=289$, [73.4%].

Overall, males had greater quadriceps strength ($p<0.01$) and reported more falls than females ($p<0.05$). However, no significant differences were noted when assessing across age groups and male and female data were combined for further analyses to increase power for statistical analysis.

2.4.2 Comparisons according to age group

Table 2.1 provides raw data for all PPA measures by age group. Significant differences were noted between age groups for overall PPA falls risk, number of reported falls and for three PPA test measures: MET, Quad and Sway ($p<0.01$).

Post hoc analysis revealed the 60-69 age group reported significantly more falls in the previous 12 months compared to all other groups ($p<0.01$). The 90+ age group had a significantly a) higher falls risk score compared to all other age groups ($p<0.01$); b) lower quadriceps strength than the 70-79 age group ($p<0.01$); and c) greater sway than the 70-79 ($p<0.01$) and 80-89 ($p<0.01$) groups. The 90+ age group also had significantly worse MET scores compared to all other groups ($p<0.01$), and the 80-89 group performed significantly worse than the two younger groups ($p<0.01$).

Decade		MET (dB)	Prop (Deg)	Quad (kg)	Rthand (ms)	Sway (mm ²)	Falls Risk	Previous Falls (n)
60-69 (n=88)	Median	19 [†]	2.8	15	349.25	2500	2.735 [†]	4
	Range	1 - 24	0.1 - 14.8	3 - 48	181.1 - 990	180 - 8778	-0.11 - 7.14	0 - 4
70-79 (n=315)	Median	19 [†]	2.6	16 [†]	340.1	2500 [†]	2.67 [†]	3 [‡]
	Range	1 - 24	0.1 - 16.8	2 - 46	198.3 - 1000	31.9 - 16800	-0.69 - 7.55	0 - 4
80-89 (n=386)	Median	18 [†]	2.8	15	356.5	2500 [†]	2.965 [†]	3 [‡]
	Range	1 - 24	0.1 - 13.8	1 - 40	159.8 - 1000	28 - 24000	-0.91 - 7.77	0 - 4
90+ (n=96)	Median	16	2.8	14	356.55	2500	3.455	3 [‡]
	Range	1 - 24	0.4 - 8.4	3 - 32	217.8 - 826	190 - 9975	-0.43 - 6.74	0 - 4
Total (n=885)	Median	18 [§]	2.8	15 [§]	353.4	2500 [§]	2.91 [§]	3 [§]
	Range	1 - 24	0.1 - 16.8	1 - 48	159.8 - 1000	28 - 24000	-0.91 - 7.77	0 - 4

Table 2.1 Median scores and ranges for all subjects according to age group for component tests of the PPA, PPA falls risk and number of self reported falls in the previous 12 months.

* Significantly different to 80-89 age group (p<0.05), [†] Significantly different to 90+ age group (p<0.05), [‡] Significantly different to 60-69 age group (p<0.05), [§] significant difference between all age groups (p<0.01).

The standard deviation of the normalised PPA measures (Z scores) varies with age (Figure 2.2), with younger age groups having significantly greater variation across test measures than the older age groups ($p < 0.05$, 3 DF). The mean normalised standard deviations (S.D) for the 60-69, 70-79, 80-89 and 90+ age groups respectively were; 0.92 (0.49), 0.94 (0.5), 0.88 (0.52) and 0.79 (0.55).

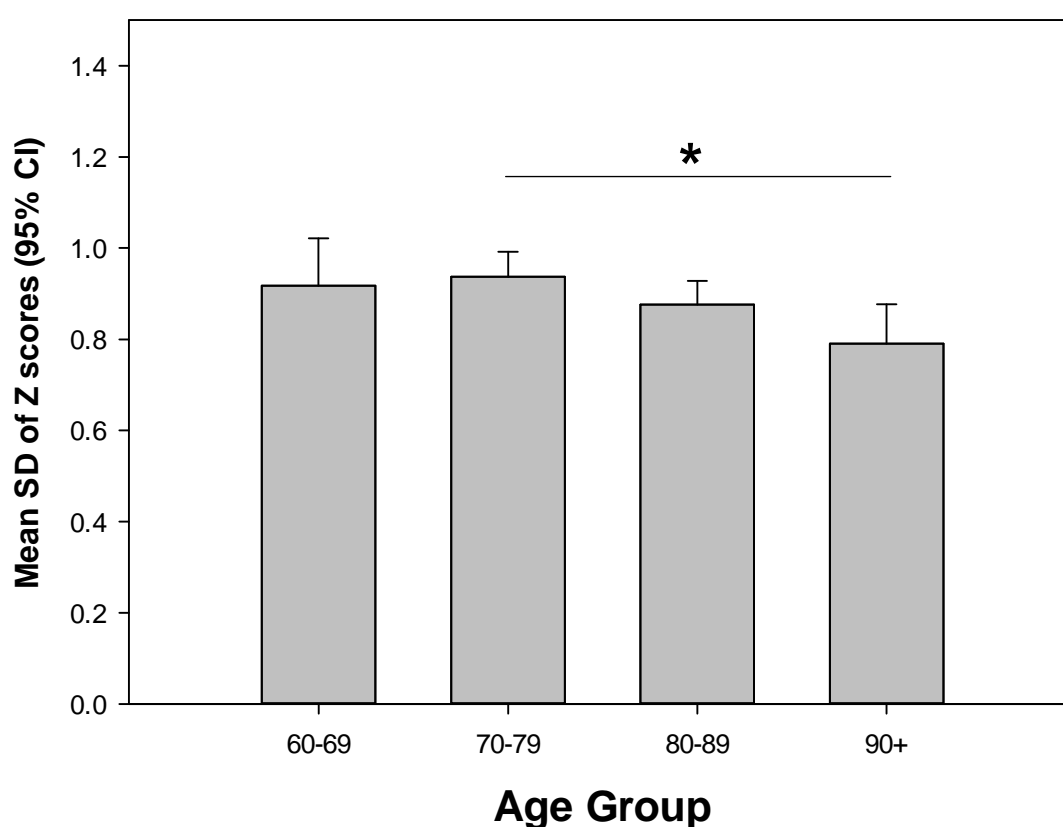


Figure 2.2 Plot of mean standard deviation (95% CI) of the Z scores computed for the five composite Physiological Profile Assessment tests.

* $p \leq .05$ (Bonferroni adjusted Mann Whitney post hoc test)

2.4.3 Comparisons according to ability to perform sway test

A large proportion of patients were unable to stand on foam with eyes open for thirty seconds ($n = 383$; 43.3%) and received the default score of

2500mm² (2 x SD). Three hundred and sixty eight (41.6%) patients performed the sway test in under this and 15.1% (n= 134) performed it in greater than 2500mm². Therefore 15.1% of subjects receive a falls risk score for this measure higher than those unable to perform the test, and who functionally have poorer balance. When stratifying patients into ability to complete and performance on the sway test, significant differences were noted between all three groups across all PPA measures, falls risk and age (P<0.01). Post hoc analysis identified that participants able to complete the test in under 2500mm² had significantly better MET, Prop, Rthand and lower falls risk (P<0.05) scores compared to those completing the test in over 2500mm². There were no differences in age or number of self reported falls.

Individuals unable to perform the test a) performed significantly worse across all PPA measures, b) had higher falls risk, c) were older than those performing the test in under 2500mm² (p<0.05) and d) had significantly weaker isometric quadriceps strength compared to those performing the test in > 2500mm² (p<0.05). Raw data is presented in Table 2.2.

When assessing variation in standard deviations across the remaining four PPA measures, the mean standard deviations (SD) for those able to perform the sway test in under 2500mm², greater than 2500mm² and unable to perform are 0.89 (0.45), 0.95 (0.52) and 0.94 (0.52), respectively. No significant difference was noted between the three groups in SD variability.

Postural Sway Test		MET (dB)	Prop (Deg)	Quad (kg)	Rthand (ms)	Falls Risk	Previous Falls (n)	Age (yrs)
able - less than 2500 (n=368)	Median	19 ^{*†}	2.4 ^{*†}	16.8 [†]	319 ^{*†}	1.9 ^{*†}	3.0	80 [†]
	Range	1.0 - 24.0	0.1 - 16.8	2.0 - 46.0	157.8-1000	- 0.91 - 7.6	0.0 - 4.0	60 - 98
able - greater than 2500 (n=134)	Median	18.0	2.8	17 [†]	357.5	3.9	3.0	80.0
	Range	1.0 - 24.0	0.1 - 14.8	3.0 - 48.0	201.4 - 929.5	1.1 - 7.8	1.0 - 3.0	60 - 101
unable to perform (n=383)	Median	17.0	3.2	14.0	362.2	3.5	3.0	82.0
	Range	1.0 - 24.0	0.1 - 12.0	1.0 - 40.0	198.3 - 992.0	1.2 - 7.3	0.0 - 4.0	60 - 98
Total (n=885)	Median	18.0 [‡]	2.8 [‡]	15.0 [‡]	353.4 [‡]	2.9 [‡]	3.0	81 [‡]
	Range	1.0 - 24.0	0.1 - 16.8	1.0 - 48.0	159.8 - 1000	-0.9 - 7.7	0.0 - 4.0	60 - 101

Table 2.2: Median scores and ranges of PPA measure scores, age and previous falls for all subjects according to ability to perform the Sway test of the PPA.

* Significantly different to those able to perform in greater than 2500mm (p<0.05), † Significantly different to those unable to perform sway task (p<0.05), ‡ Significantly different across groups (p<0.01).

2.5 Discussion

This study aimed to compare the PPA falls risk, variability of PPA measures, individual impairments between age groups of patients attending an integrated falls service and to investigate the ability of older adults to perform the sway test. Findings showed significant differences in PPA measures between age groups. The discussion will focus on two main themes: 1) differences in PPA test measures and variability between age groups and 2) ability of older adults to complete the postural sway measure of the PPA test.

2.5.1 Differences in PPA test measures and variability between age groups

Older age groups performed significantly worse and had significantly higher PPA falls risk than younger groups, but reported fewer falls. Conversely, younger age groups performed better (with lower PPA falls risk) yet reported greater numbers of falls.

Impairment variability changes with age. Greater variability is noted in younger individuals (60-69 and 70-79) while a concomitant reduction in variability and global reduction in function is noted with advancing years. This may indicate that in older adults, a consistent reduction in function (associated with frailty) across multiple measures results in impaired balance function, and therefore increases falls risk. However, greater variability in the younger age groups may be associated to specific disease processes and as a result inconsistent but specific PPA impairments may account for the increased variability and increased falls rate. The PPA has previously been

shown to identify changes in gait parameters in older adults (Callisaya et al. 2009) but further measures of gait and / or balance such as preferred gait speed, tandem walk or single leg stand would have provided a useful comparison between groups to correlate PPA measures with functional balance performance. However, these tests are not routinely used in the study falls clinics and so data is not available. Also, the collected clinical information used to direct patient management and rehabilitation such as stroke, diabetic neuropathy, or postural hypotension would have enriched our study data. However, this clinical data was not recorded systematically enough for inclusion in this study.

Differences in reported falls history and variability in PPA measures with age may be due to any number of factors associated with falls in older adults which are not directly assessed by the PPA including cognitive impairment, maladaptive behavioural patterns associated with fear of falling (Bruce et al. 2002) or impairments in vestibular function.

Retrospective collection of falls history, as in our study, may influence subject recall (Fleming et al. 2008) and although falls recall over the previous six months is reasonably reliable, prospective data with consistent definitions is better (Ganz et al. 2005). Self-reported falls data within the *SLIPS* clinics is collected by numerous clinicians with no standardised phrasing of questions regarding falls history or definition of falls. The inevitable inconsistency may have affected the accuracy of the falls report rate which could also be influenced by cognition. Older fallers with cognitive impairment

under-report falls rate and perform worse than age-matched controls in the PPA (Lorbach et al. 2007). Thus cognition may have contributed to our results as the eldest age group, which reported fewest falls had a higher PPA falls risk.

Lifestyle choices for the older age groups who may have restricted their daily movements and activities due to postural instability, possible previous falls, and fear of falling (Bruce et al. 2002) may have also influenced results. However, cognitive function, balance confidence and ADL performance were not assessed in this study; and as such no conclusions can be drawn regarding whether these factors contribute to the current findings.

The inclusion criteria may also have created a selection bias. All subjects had been identified as at risk for falling following pre-screening with the TUG, with a cut off of 15s selecting those requiring PPA testing. As gait speed decreases with age (Bohannon 1997), the likelihood of being tested increases with age. Therefore younger adults that are exceeding this threshold may be more likely to present with specific impairments impacting upon gait and falls rates, compared to global reductions in function in more elderly individuals. Therefore our results need to be interpreted with caution.

Many patients with confirmed vestibular disorders fall and are at risk for injury (Herdman et al. 2000; Whitney et al. 2000). The 2001 – 2004 US National Health and Nutrition Survey showed that 69 million (35.4%) Americans over age 40 had vestibular dysfunction and the odds significantly

increased with age (Agrawal et al. 2009). Furthermore, studies consistently report that older adults referred for a falls risk assessment or presenting to an Emergency Department after a fall have impaired vestibular function on clinical testing (Kristinsdottir et al. 2000; Kristinsdottir et al. 2001; Lawson et al. 2005; Zur 2006; Lawson et al. 2008). Vestibular function is not routinely tested in our *SLIPS* clinics, and no standardised validated approach exists in the falls literature or NICE guidance. Inquiry about dizziness or vertigo is diagnostically inadequate as patients either do not report these symptoms (Lawson et al. 2005; Lawson et al. 2008) or report similar levels to age-matched non-fallers (Murray et al. 2005). In addition, benign paroxysmal positional vertigo (BPPV), which accounts for 17-42% of patients with vertigo, is often unrecognised in older adults (Lawson et al. 2005) due to an atypical presentation of unsteadiness or dizziness as opposed to the typical history of brief vertigo attacks (<30s) triggered by a change in head position. It is suggested that vestibular function testing may strengthen falls risk assessment, prevention, and rehabilitation.

2.5.2 Clinical validity of the PPA sway measure

Those able to perform the sway test in less than 2500mm² perform significantly better across all PPA measures (except quadriceps strength in >2500mm²) and have a lower falls risk than all other groups. Those that cannot perform the sway test have weaker quadriceps than those that can, which may have significant functional implications for this group. Quadriceps strength is significantly associated with ability to sit-to-stand (Lord et al. 2002) and walking speed (Bohannon 1997), indicating possible impaired

functional ability and frailty in this group. Unfortunately, measures of functional ability and gait speed were not collected in this study.

There is a trend for those unable to perform the sway test to perform worse on individual PPA measures, yet have lower PPA falls risk than those that perform the sway test in greater than 2500mm². Those able to complete the test are receiving higher PPA falls risk scores as their sway area is greater than the default score (2 x SD) given to those unable to complete the task. This artificially elevates their score and incorrectly classifies those able to complete the task as at higher risk than those that cannot maintain stability on foam with eyes open. This would cast doubt on the PPA scores of 58.4% of patients tested in this clinic, limiting the usefulness of the PPA as a measure of postural stability.

2.6 Conclusions

Younger individuals reported significantly more falls yet had significantly lower falls risk than the oldest age group which reported significantly less falls. The oldest (80+) adults have reduced variability in PPA measures consistent with global reductions in function and frailty; younger individuals have significantly greater variability across PPA measures, indicating that focal pathology within specific PPA test measures may be the cause for falls. It is suggested that current findings be considered when organising falls rehabilitation programmes for younger and older individuals.

Individuals that complete the sway test in $>2500\text{mm}^2$ receive higher scores for sway than those unable to maintain stability in this test. This artificially elevates the sway score contributing to overall PPA falls risk, increasing PPA falls risk compared to an individual that is unable to complete the sway test.

The PPA incorrectly classifies 58.4% (n= 502) of subjects on the sway measure. Therefore the clinical validity of the PPA may be questionable.

Chapter 3. A complex bi-modal spatial multi-task alters postural prioritisation in healthy older adults

3.1 Abstract

Background

Many daily activities require appropriate allocation of attention between postural and cognitive tasks (i.e. dual-tasking) to be carried out effectively. Processing multiple streams of spatial information is important for everyday tasks such as road crossing. However, the effect of complex bimodal spatial multi-tasks on postural prioritisation has not been investigated.

Methods

Fifteen community-dwelling healthy older (mean age=78.3,male=1) and twenty younger adults (mean age=25.3,male=6) completed this novel bimodal spatial multi-processing test. The paradigm provides contextually similar spatial information via separate sensory modalities. Two tasks, a temporally random visually-coded spatial step navigation task (VS) and a regular auditory-coded spatial congruency task (AS) were performed independently (Single task) and in combination (Multi-task). Response time, accuracy and dual-task costs (DTC's) were determined.

Results

A significant 3-way interaction between task type (VS vs. AS), complexity (single vs. multi) and age group was observed for both response time ($p<.01$)

and response accuracy ($p < .05$) with older adults performing significantly worse than younger adults. DTC's were significantly greater for older compared to younger adults in the VS step task for both response time ($p < .01$) and accuracy ($p < .05$) indicating prioritisation of the AS over the VS stepping task in older adults. Younger adults display greater AS task response time DTC compared to older adults ($p < .05$) indicating VS task prioritisation in agreement with the posture first strategy.

Conclusion

This novel test displays alterations in postural prioritisation not previously described in older adults. These findings may have clinical implications for falls assessment and rehabilitation.

3.2 Introduction

Age-related changes in strength, peripheral sensation, vision and vestibular function can have a detrimental effect on postural stability and are commonly associated with falls (Lord et al. 1991; Lord and Ward 1994; Kuo et al. 1998). However, maintaining postural stability also requires the allocation of attention, with the amount required varying according to the nature and difficulty of the task, the person's age and functional balance abilities (Woollacott and Shumway-Cook 2002). Successful completion of a (balance) task requires both motivation and planning. These aspects are governed by executive function, a group of higher cognitive processes involved in a person's ability to organize thoughts, prioritise tasks, make decisions, and efficiently manage time (Lezak 2005). Deficits in executive function, memory, and attention are common with increasing age and are associated with impairments in postural control, dual-tasking ability, and an increased falls risk (Redfern et al. 2001; Ble et al. 2005; Coppin et al. 2006; Liu-Ambrose et al. 2009).

Many daily activities involve maintaining balance while performing at least one other concurrent task (e.g. walking and talking) whereby attentional resources must be appropriately divided between maintaining postural control and cognitive performance i.e. dual tasking. Dual-tasking postural control is the norm rather than the exception in daily life and is crucial for maintaining normal day-to-day function. Experimental dual-task paradigms compare baseline performance on individual tasks to performance when two tasks are performed simultaneously. Postural tasks can include standing

(Redfern et al. 2001; Teasdale and Simoneau 2001; Woollacott and Vander Velde 2008), stepping (Brauer et al. 2002; Sturnieks et al. 2008), gait (Lundin-Olsson et al. 1997) or obstacle crossing (Silsupadol et al. 2009) with the probe more commonly a cognitive task, such as an auditory stroop task (Silsupadol et al. 2009). One such dual-task paradigm combines the choice stepping reaction test (CSRT) that consists of a volitional directed step protocol utilizing illuminated panels on the floor (Lord and Fitzpatrick 2001) with either a spatial or non-spatial task. CSRT times were significantly increased by simultaneous performance of spatially loaded tasks, while no increase was noted for non-spatial tasks (Sturnieks et al. 2008). Step responses (postural tasks) are considered to be prioritised above cognitive tasks if the two tasks are concurrent. This indicates preferential preservation of posture, termed the posture first strategy (Shumway-Cook et al. 1997; Brauer et al. 2002). Dual-task studies consistently show that while younger adults are generally able to perform both tasks effectively, older people display decreased dual-task performance as they attempt to preserve the postural task. Dual-task impairments may include slower task response times, reduced accuracy, gait speed and/or step length (Lajoie et al. 1996; Brauer et al. 2002; Toulotte et al. 2006; Sturnieks et al. 2008).

Dual-tasking models rely on a number of assumptions: 1) central processing capacity is limited, 2) performing a task requires a given proportion of this capacity, and 3) if two tasks performed simultaneously exceed total capacity, then performance in one or both of them will be negatively affected (Lajoie et al. 1996). It has been suggested that dual-task effects occur due to an

increased competition for central processing resources (Maylor and Wing 1996). This appears particularly true during visuo- or auditory spatial tasks compared to non-spatial tasks (Barra et al. 2006; Sturnieks et al. 2008; Green et al. 2010). However, current tests do not require significant bi-modal spatial dual-tasking, such as processing visually coded spatial information, while dealing with auditory coded spatial information. Multiple streams of information that relate to the spatial domain need to be processed in everyday life. Visual and auditory spatial cues are often utilized in conjunction for navigation in complex environments, such as crossing the road. This is a typical situation where older adults perform worse than younger adults (Dommes and Cavallo 2011; Neider et al. 2011). Therefore, providing bi-modal tasks (i.e. those that simultaneously deliver contextually similar information via separate sensory modalities) may provide greater information on task prioritisation than standard dual-task protocols.

We hypothesize that a complex bi-modal spatial multi-task, i.e. providing two distinct spatial cognitive tasks delivered via separate sensory modalities alongside a postural task, places a greater demand on available processing resources compared to traditional dual tasking paradigms and provides a protocol for assessing attention switching between two spatial tasks. Therefore, using a bi-modal spatial multi-task paradigm, which aims to replicate a situation when reactive volitional postural decisions are required, should make it easier to observe differences between task prioritisation strategies.

In this complex multi-task paradigm, one visually coded spatial task (VS) is used to initiate a directed step (a step navigation task) whilst a secondary auditory coded spatial task (AS) is utilized as a probe to determine the dual-task effect. We believe this paradigm may provide a much greater challenge to physically active older adults and the aim of this study is to investigate whether the strategies employed for bi-modal spatial multi-tasking differ between healthy younger and older adults. Using separate sensory modalities to provide the spatial tasks is a unique approach to reduce sensory processing conflicts, so that measured dual task effects are a spatial processing conflict rather than conflicts in sensory processing. The study will specifically assess the effect of combining two concurrent spatially loaded cognitive tasks on response times, accuracy and task prioritisation strategies in healthy younger and older adults. The information obtained may provide an insight into the increased risk for falls in older adults when a rapid adaption of postural strategy is necessitated, a situation commonly encountered in daily life.

3.3 Materials and Methods

3.3.1 Participants

Independently mobile, community dwelling younger ($n=20$, $M= 6$; mean 25.3 years ± 3.43 , age range 18-35) and older adults ($n=15$, $M= 1$; mean 78.3 ± 7.54 years, age range 65-91) participated in this study, which had received local research ethics committee approval, after providing written informed consent. Subjects had no self-reported history of falls within the previous 12

months, vestibular or neurological disease, dizziness, hearing loss, reported deficits in colour vision acuity, or any acute orthopaedic injury. Younger subjects were recruited via circular email to students attending King's College London, London, UK, and older adults were recruited from general exercise classes provided by Southwark Council (London, UK). Participants with scores outside the normative range on the Vertigo Symptom Scale ($<0.3/4$) (Yardley et al. 1992) and the Abbreviated Mental Test for cognitive function ($\geq 8/$) (28) were excluded.

3.3.2 Experimental apparatus and techniques

A modified video game dance mat measuring 92cm by 81cm containing four touch sensitive coloured squares (16cm x 16cm) placed anteriorly, posteriorly and medio-laterally of a central square (22cm x 22cm), was used to measure reactive step response times for the visual coded spatial task (Figure 3.1). Please see appendix 1 for the developmental work to finalise the protocol for the multi-task test.

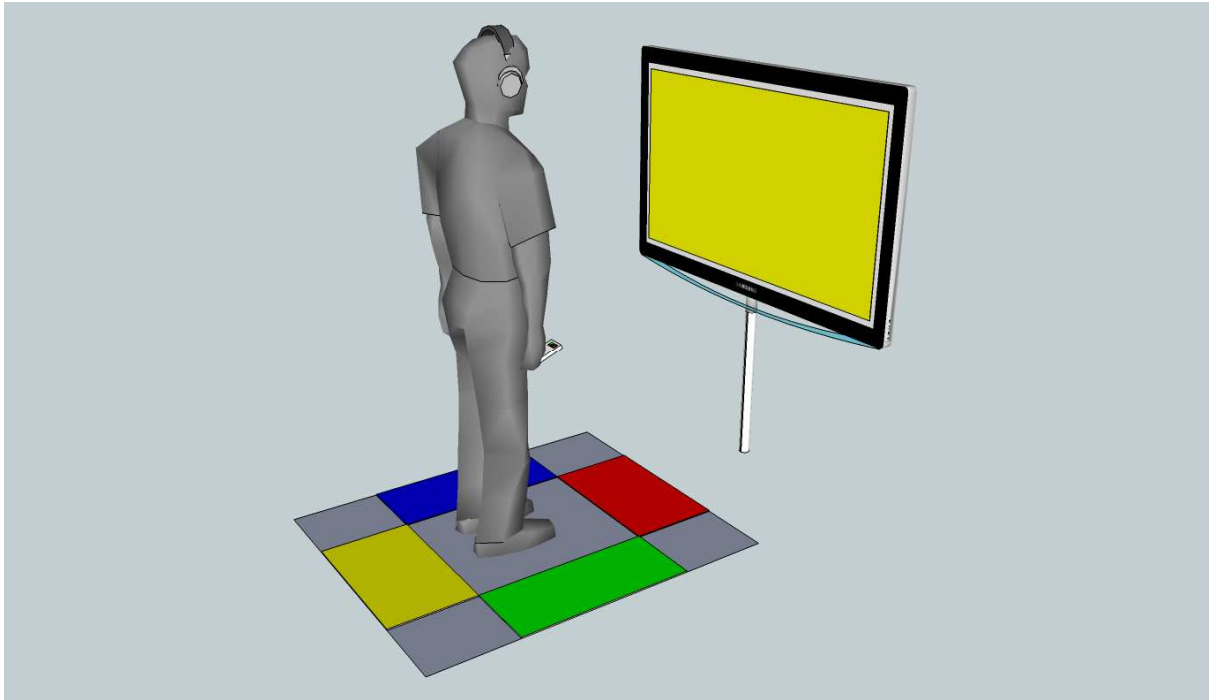


Figure 3.1 Diagrammatic representation of the experimental set up for the stepping task

3.3.3 Task ordering

The two tasks were performed independently (single VS and single AS) and in combination for the bi-modal spatial multi-task paradigm. Task sequence was randomised to reduce order and learning effects. Practise trials were not performed, as this test intended to determine an individual's response to a novel sensory integration challenge and did not want it to be affected by potential differential abilities to learn complex tasks between groups. Subjects were provided with comprehensive instructions and were able to practise the stepping movement to words spoken by the investigator to familiarise themselves with the required movements, however, practise trials involving VS and AS task decoding were not performed. Subjects were not provided with explicit instruction to prioritise one task over the other, as the aim was investigate whether the step task would automatically be prioritised in accordance with posture first.

3.3.4 Visual Coded Spatial Task (VS) (Stepping task)

Subjects stood barefoot in the mat's centre with feet hip-width apart looking ahead at a widescreen LCD TV (109cm diagonally corner to corner) display placed 80cm away at eye level. When the display changed colour, participants were instructed to step as quickly and safely as possible with one foot onto the corresponding coloured square on the mat and then return the foot to the original position within the centre square and await the next screen colour change. Screen colour changes occurred quasi-randomly every 6 to 13 seconds so that six steps in total were performed per condition. Stimulus presentation was randomized for both step direction (anterior,

posterior, and lateral) and time, but at least one step was performed in each direction per condition. After each trial the mat was rotated 90° clockwise to negate any learning effect from prior knowledge of the colour square positions. Each condition lasted for 1 minute.

3.3.5 Auditory Coded Spatial Task (AS)

The auditory spatial task utilized a spatial stroop design presented through wireless stereo headphones. The subject responded to unilateral aural stimuli by pressing one of two buttons (tick / cross) on a handheld wireless keypad (Barra et al. 2006; Green et al. 2010). The stimuli consisted of the words “Left” and “Right” delivered through either the left or right headphone speaker. If the word matched the side it was presented to (i.e. “Left” in the left ear) the result was congruous and therefore the appropriate response was to press the button with a tick icon on it as rapidly as possible. If incongruous, then pressing the button with a cross icon was the appropriate response. The total task duration was 1 minute and the aural stimulus was presented every 4.5 seconds.

3.3.6 Data Recording

Two custom programs were developed by Dr Jeroen Bergmann in Matlab 7.4 (MathWorks, Natick, MA) to provide 1) the cognitive tasks and 2) analysis of the raw data signals for both tasks. The cognitive tasks were provided via a single Matlab program which synchronized both tasks. Responses were detected as either a button press on a hand held keypad, or a step surpassing a pressure threshold on the touch sensitive mat. The response

time from either the visual or auditory stimulus was computed and the algorithm subsequently determined if the response given was the correct one. If the subject did not provide any response, the maximum time for that particular section was taken and the response was automatically rated as inaccurate. A Labjack U3 (Labjack Corporation, Lakewood, Colorado, USA) analogue to digital converter (sample rate 200Hz) was used to integrate the mat with the recording PC.

3.3.7 Statistical Analysis

Statistical analysis was performed using SPSS version 17 (SPSS Inc, Chicago, Ill). Mean and standard deviation are presented for response time and accuracy. Data was non-normally distributed, therefore it was base-10 log transformed prior to ANOVA analysis. A repeated measures ANOVA was used with task type and task complexity as separate 2 level factors as age group is a between-subject factor and both task type (visually coded / auditory coded) and task complexity (single/multi) are within-subject factors. Partial η^2 from planned contrasts were used to determine effect size. Dual-task costs (DTC) i.e. the percentage change in response time and response accuracy due to the multi-task condition were calculated for both response time and response accuracy for the auditory coded spatial task and visually coded spatial task using the following equation (Menant et al. 2010; Van Impe et al. 2011):

$$\text{Dual task cost (\%)} = 100 * (\text{Multi task} - \text{Single task} / \text{Single task})$$

Positive DTC values indicate either an increase in response time or accuracy in the multi-task condition. Within-group differences in DTC were assessed using the Wilcoxon signed rank test and between-group differences using Mann-Whitney tests as this data was non-normally distributed and could not undergo transformation due to negative values. Pearson's rho ($r = \frac{Z}{\sqrt{N}}$) was calculated to determine effect size of the differences in DTC (Field 2005). This method of separately analysing DTC to other collected measures has been previously described (Brauer et al. 2002; Van Impe et al. 2011). Data are presented as mean \pm standard deviation for response times and accuracy, and median and inter-quartile range for DTC's. A separate analysis with all error responses removed is supplied in Appendix 2. For all tests statistical significance was assumed if $p < .05$.

3.4 Results

3.4.1 Response times

The visually coded spatial task (VS) produced significantly longer ($F_{1,33} = 24.085$, $p < .01$, $\eta^2 = 0.422$) response times than the auditory coded spatial task (AS) (Table 3.1). Task complexity (i.e. single/multi) also had a significant effect on response times ($F_{1,33} = 141.094$, $p < .01$, $\eta^2 = 0.81$), with the complex multi-task condition eliciting longer response times. There were significant 2-way interactions between age group and both task type and complexity. Older adults have significantly longer response time when a) performing the VS task ($F_{1,33} = 8.093$, $p < .01$, $\eta^2 = 0.192$) and b) performing dual tasks ($F_{1,33} = 4.875$, $p < .05$, $\eta^2 = 0.129$) than the younger adults. No significant interaction

was noted between task type and task complexity ($F_{1,33} = 0.018, p = .894, \eta^2 = 0.001$), however the 3-way interaction between age group, task type and task complexity was significant ($F_{1,33} = 13.707, p = .001, \eta^2 = 0.293$) highlighting the fact that age significantly influences this interaction, with older adults increasing response times more than younger adults. When plotting AS and VS response times for each individual task prioritisation strategies were able to be visualised (Figure 3.2)

		Response Time (s)				Response Accuracy (%)			
		Single	Dual	Single	Dual	Single	Dual	Single	Dual
		AS	AS	VS	VS	AS	AS	VS	VS
Younger	Mean	1.22	1.93	1.56	1.84	97.73	86.82	96.67	99.17
(n=20)	SD	0.32	0.47	0.53	0.47	5.0	13.02	6.84	3.73
Older	Mean	2.03	2.71	2.48	4.88	78.18	61.82	94.44	58.89
(n=15)	SD	0.65	0.48	0.76	2.32	20.27	25.53	12.06	28.78

Table 3.1 Mean (\pm SD) response time (s) and accuracy (%) for single task and dual task conditions for younger and older adult groups.

VS – Visuo-spatial task, AS – Audio-spatial task

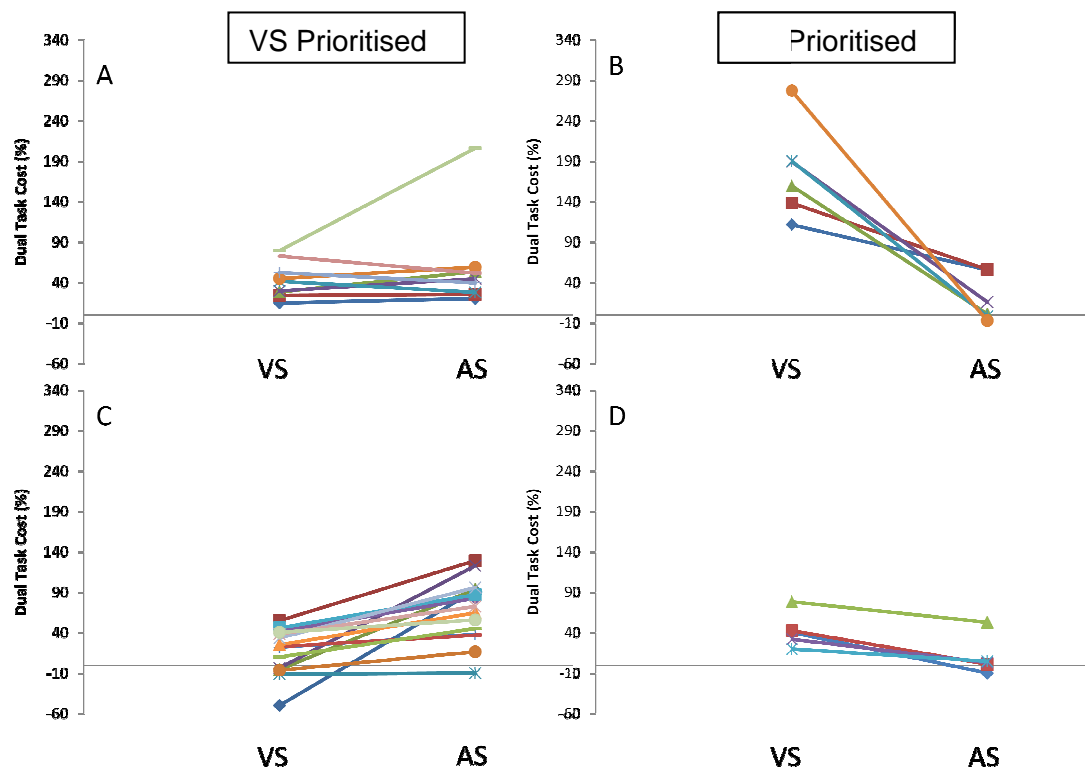


Figure 3.2 Raw individual level dual task cost data according to task priority in older adults (A/B) and younger adults (C/D). It is possible to observe individuals that are preferentially prioritising the AS task over the VS task (B/D).

VS – Visuo-spatial task, AS- Audio-spatial task.

Dual-task costs (DTC) were significantly different between age groups, with greater cost noted in the younger compared to the older age group for the auditory coded (AS) spatial task ($z=-1.967$, $p<.05$, $r = 0.33$). The converse is seen for the visually coded (VS) spatial task where older adults display significantly greater DTC than younger adults ($z=-3.133$, $p<.01$, $r = 0.53$). Significant within-group differences were observed between VS and AS DTC's for younger adults ($z=-3.248$, $p<.01$, $r = 0.73$), with AS DTC's greater than VS. No difference in DTC's between AS and VS was observed in older adults ($z=-1.533$, $p=.125$, $r = 0.4$) (Figure 3.3).

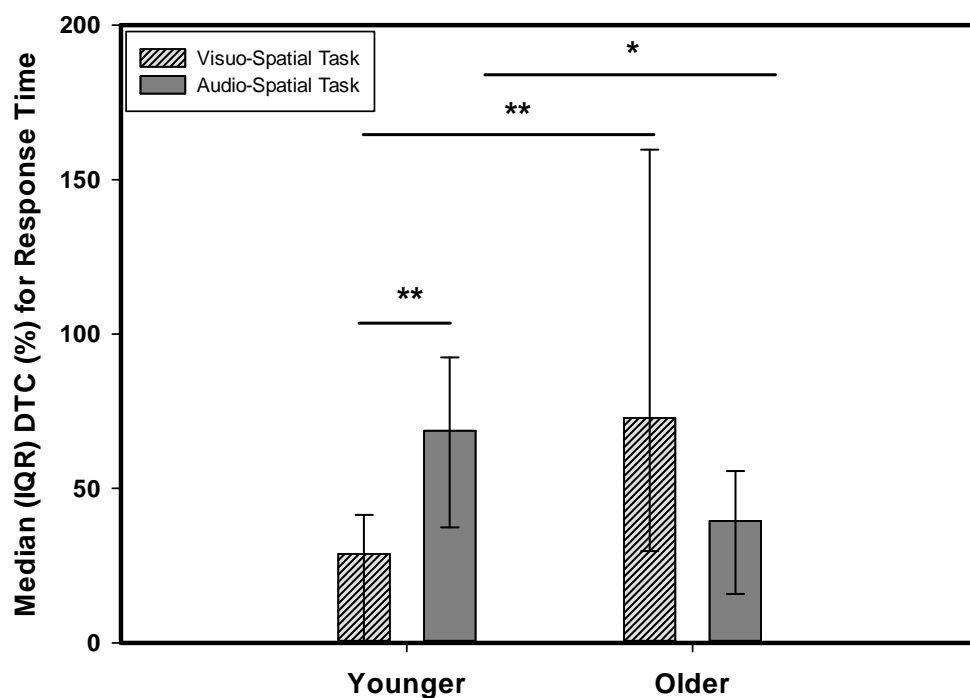


Figure 3.3 Median (IQR) Dual Task Costs for response time in the Visuo-Spatial and Audio-Spatial tasks for younger and older adults. * $p<.05$, ** $p<.01$

3.4.2 Task Accuracy

Task complexity significantly effects response accuracy with greater accuracy demonstrated during the single task condition ($F_{1,33} = 30.617$, $p < .01$, $\eta^2 = 0.481$) (Table 3.1). A significant interaction was also noted between task complexity and age group for the multi-task condition, whereby accuracy was significantly lower for older adults ($F_{1,33} = 19.813$, $p < .01$, $\eta^2 = 0.375$). Although no significant 2-way interaction between task type and task complexity was noted ($F_{1,33} = 0.539$, $p = .468$, $\eta^2 = 0.016$), a 3-way interaction between task type, task complexity and age group was observed for accuracy ($F_{1,33} = 4.775$, $p < .05$, $\eta^2 = 0.126$) indicating that older age significantly modifies the interaction between task type and task complexity. This 3-way interaction identifies that older adults are less accurate in the multi-task conditions with VS responses most affected.

The DTC for response accuracy during the VS spatial task was significantly different between age groups ($z = -4.419$, $p < .01$, $r = 0.75$) with older adults experiencing a greater DTC. There was no significant DTC difference between age groups for the auditory coded spatial task ($z = -1.315$, $p = .189$, $r = 0.22$). Significant within-group differences between AS and VS tasks for response accuracy DTC's were observed in younger adults ($z = -2.847$, $p < .01$, $r = 0.64$) with Highest DTC's for the AS task. No difference between task DTC's was noted for older adults ($z = -1.25$, $p = .211$, $r = 0.32$) (Figure 3.4).

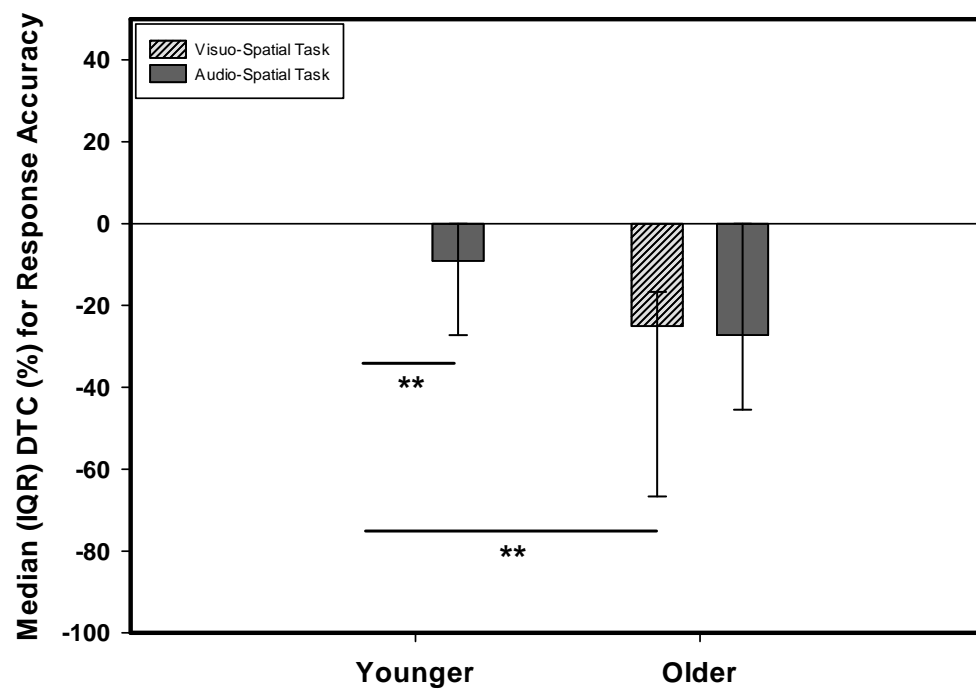


Figure 3.4 Median (IQR) Dual Task Costs for response accuracy in the Visuo-Spatial and Audio-Spatial tasks for younger and older adults. * $p < .05$, ** $p < .01$

3.5 Discussion

This study aimed to investigate task prioritisation strategies in younger and older adults when performing a complex bi-modal spatial multi-task test requiring the processing of two independent, spatially loaded cognitive tasks. Results indicate that some healthy older adults fail to prioritise postural tasks when performing a novel bi-modal spatial multi-task indicating deviation from the 'posture first' strategy that may contribute to elevated falls risk.

3.5.1 Effects of task complexity

Older adults were significantly slower in responding to cognitive and stepping tasks in the single task condition, consistent with a multitude of older vs. younger adult studies (Luchies et al. 1999; Der and Deary 2006; Meadmore et al. 2009) and is attributed to a reduction in overall processing speed (Park et al. 2002) when single tasking. Furthermore, our findings are in accordance with previous studies showing increased task response time and poorer performance with older age when dual tasking (Maylor and Wing 1996; Huxhold et al. 2006).

Older adults are more impaired by task complexity than younger adults, with the bi-modal spatial multi-task test eliciting significantly greater response time and lower response accuracy in older adults. The DTC for the AS task response time is significantly greater (i.e. worse) in younger (68.7%) compared to older adults (39.6%). Conversely, the opposite is seen during the VS task, where DTC is significantly greater for older (72.9%) compared to younger adults (28.8%). A similar significant pattern is observed for the

DTC with regards to VS task response accuracy, where accuracy does not change for younger adults (0%) but deteriorates for older adults (-25%).

Our findings indicate that younger adults prioritise VS stepping responses to the detriment of the AS probe task, as would be expected with adoption of the posture first strategy. This is in agreement with many dual-task studies reporting prioritisation of the postural task (Brauer et al. 2002; Siu and Woollacott 2007; Sturnieks et al. 2008). In older adults the opposite is seen; DTCs are lowest for the AS task and the VS task indicating a downgrading of the postural task and an alteration in the posture first strategy in some older adults.

Similar trends have previously been noted in patients with Parkinson's Disease, where posture is not prioritised during complex dual-task situations (Bloem et al. 2006), but this has not, to our knowledge, explicitly been observed in healthy older adults before. A possible alternate explanation may be that older adults are prioritising posture, and are increasing response times due to increased caution. However, a significant 3-way (age*type*complexity) interaction indicated greatest reduction in task accuracy for the VS task. If older adults were more cautious and investing greater care and attention to the VS task, these reductions in VS task accuracy should not have been observed.

Our study provides clear evidence for impairment of postural task prioritisation in some healthy older adults, similar to that recently observed

during locomotion where gait speed decreased during the dual-task test but cognitive performance improved on 50% of collected measures (Hall et al. 2011). The authors attribute this to possible matching of gait speed to the cognitive task or increased attention to the cognitive task. This may have occurred as cognitive tasks were scored and identified as an outcome whereas gait speed was not identified as an outcome measure to subjects. Our study used defined probe timings and measured accuracy and response time for each task, therefore negating the effect of directed attention or temporal matching of tasks. This suggests that altered postural prioritisation strategies (i.e. a modification of posture first) may be responsible for the greater degradation in VS stepping task performance in some older adults.

Dual-tasking interference can occur under various conditions and there may be a number of factors causing modification of the posture first strategy observed in older adults in this study. For example, additional tasks may exceed a finite processing capacity (capacity sharing), require parallel processing in the same neural network (bottlenecking), share similar resources (multiple resource) (Yogev-Seligmann et al. 2008) or attention switching may be impaired (Siu et al. 2009). The authors believe that the observed deviation from posture first in older adults is most likely due to a reduced ability for attention switching in older adults between the independently presented bi-modal spatial cues.

3.5.2 Effects of Attention switching

Cognitive function impacts upon dual-task ability, with impairments in working memory, divided and focused attention significantly impacting upon gait speed when simultaneously performing complex cognitive tasks (Hall et al. 2011). Imaging studies have identified increased dorsolateral prefrontal cortex activity in older adults in executive function tests of working memory (Turner and Spreng 2011) thought to be responsible for the maintenance of attentional sets (Van Impe et al. 2011). A number of studies have indicated that attentional capacity and flexibility in attention switching (i.e. shifting attentional resources from one task to another) may be most important for dual-task performance in older adults (Maki et al. 2001; Siu et al. 2009; Berg and Murdock 2011).

This study tested attention switching between a predictable and temporally regular auditory coded spatial task and a temporally quasi-random (every 6-13 seconds) visually coded spatial task, with older adults displaying reduced flexibility in attention switching, consistent with the results of Siu *et al*, (Siu et al. 2009). However, our findings are not consistent with reported data in healthy and balance impaired older adults (e.g. (Brauer et al. 2002; Siu et al. 2009)) where the postural task is prioritised to the detriment of the probe task, but rather the opposite is seen where the temporally regular AS probe task is prioritised in some older adults. The mechanism responsible for this change in prioritisation was not assessed in the current study, but we postulate that the regularity and predictability of the AS task made attention switching to the VS task more difficult in older adults, where attentional

capacity is generally lower. Support for this hypothesis comes from recent findings showing that attention demanding auditory tasks, such as talking on a mobile telephone significantly impact on street crossing in older adults, with delayed cross initiation rather than reduced gait speed (Neider et al. 2011).

Another possible explanation for the failure to adopt the posture first strategy in some older adults may be due to the use of a directed volitional step in our test paradigm. Studies using static standing and perturbation based protocols provide less additional spatial cognitive processing above the probe task. These protocols utilize more reflexive driven postural responses and therefore may be less affected by other factors such as balance confidence and postural stability. Individuals with lower balance confidence may be less likely to take a volitional step, although, we may expect individuals with perceived or actual impaired postural stability to invest more attention and cognitive resources toward the stepping rather than the probe task as reported by Sturnieks et al (Sturnieks et al. 2008). In that study, spatial tasks were found to significantly affect volitional choice stepping response times, but not step accuracy; however, the stepping task used was less challenging and required less spatial decoding than in our protocol as subjects were required to step on an illuminated panel on the floor rather than decipher a coded visual stimulus for step direction. Our protocol required processing of independent bi-modal spatial information to elicit a volitional postural response (VS) or a coded button press (AS); therefore impairments in response times may be due to sharing of similar cognitive resources required for spatial processing. However, due to the higher

frequency and temporal regularity of AS stimulus presentation, the increased level of incorrect responses and increased response times in the VS step task, we postulate that impaired attention switching is most likely responsible for observed deficiencies in older adults.

3.5.3 Postural control and implications for practice

The observed interference of the probe task on postural response time and accuracy has demonstrated that the posture first strategy may be decremented by a suitably difficult dual-task paradigm. An interesting finding within the older adult group was the greater variability and spread in multi-task response times; reflecting different attentional prioritisation strategies in individual older adults, and may provide evidence that the shift from posture first to posture second may be better measured as an index rather than an absolute. The cause of variability can be observed in individual level data (Figure 3.2), where older adults either prioritise the VS task (Figure 3.2a) or the AS task (Figure 3.2b), with greater variability in selection of strategy between individuals. This change in selection of strategy warrants further investigation to determine whether it has any interaction with balance confidence, falls risk or falls in older adults. Variability in balance confidence and physical function may also affect step responses, where those with impaired balance or reduced confidence may be less willing, and therefore slower to step than those with greater function and confidence.

This study may provide an explanation why seemingly fit and healthy older adults may feel more unsteady or begin to experience falls if the current

cognitive task requires sufficient attention. Therefore this quick to administer and portable test may have future application for falls risk assessment and multi-task training in older adults.

3.5.4 Study limitations

The older adult group had significantly greater proportions of females than the younger group. This may have an effect on increasing the variability in reaction time in the older adults, as choice reaction time variability has been demonstrated to be higher in females than males (Der and Deary 2006). However, variability in this study may also be in part due to different prioritisation strategies.

There are also higher levels of inaccuracy in the older adults with six older adults having greater than 50% errors in responses. This could have potential limiting effects on clinical usefulness as all older adults were healthy non fallers. However, this complex test allowed for alterations in posture first to be observed in a subset of this population. It was also not possible to determine the direction of delayed steps or errors. Future protocols will record this data and will be designed to be simpler, to allow for easier observation of interactions

3.6 Conclusion

Bi-modal spatial multi-tasking highlights deficiencies in attention switching ability in healthy older adults, where more temporally regular cognitive tasks are prioritised in the multi-task condition rather than the postural task. These

findings may have clinical implications for falls assessment and rehabilitation in older adult fallers.

Chapter 4. A comparison of balance, dizziness, and falls risk in older-adult fallers and age-matched patients with a peripheral vestibular disorder: A pilot study.

4.1 Abstract

Background

Recent findings show that >70% of older adults referred for a multi-factorial balance assessment have a vestibular disorder. It is unknown whether this proportion differs compared to a healthy population.

Design

Case-controlled study to determine (1) vestibular dysfunction in older adult fallers (Group F) and healthy controls (Group H); (2) whether Groups F and H differ from older adults referred for vestibular function testing (Group PV) in reported falls, symptoms, vestibular function, and postural control.

Setting

Tertiary falls and neuro-otology clinics, London, UK.

Participants

Community-dwelling older adults experiencing: (a) >2 unexplained falls within the previous 12 months (Group F, n=25), (b) a confirmed peripheral vestibular disorder (Group PV, n=15) and (c) healthy non-fallers (Group H, n=16).

Measurements

All participants completed quantitative vestibular function tests, the Functional Gait Assessment (FGA), Physiological Profile Assessment (PPA) and subjective measures for vestibular symptoms (i.e. giddiness), balance confidence and perceived ability for daily activities (ADLs).

Results

Eighty-percent (20/25) of Group F had clinically significant vestibular dysfunction compared to 18.8% (3/16) for Group H ($p<.01$). Group F performed worse in complex gait tasks (FGA), experienced a greater number of falls and reported lower functional ability in ADL's than both Groups H and PV ($p<.05$). Vestibular symptom scores showed no significant difference between Groups F and PV.

Conclusion:

Vestibular dysfunction is significantly more prevalent in older adult multiple fallers vs. non multiple fallers. Individuals referred to a falls clinic are older, more impaired and report more falls than those referred to a neuro-otology department. A greater awareness of vestibular impairments may lead to more effective management and treatment for older adult fallers.

4.2 Introduction

Postural control is a complex function requiring central processing and integration of visual, vestibular and somatosensory system afferents leading to an organised control of motor responses (Vouriot et al. 2004). Age-related decline in physical and sensory functions alongside an impaired ability to integrate sensory information appropriately is well-documented in older adults (Lord and Ward 1994; Lord and Clark 1996; Baloh et al. 2001; Baloh et al. 2003; Agrawal et al. 2009) and may lead to impaired balance function and an increased falls risk.

Longitudinal studies have identified reduced vestibular function with advancing years (Baloh et al. 2001; Baloh et al. 2003). Until recently however, vestibular dysfunction prevalence and its relationship with falls risk in older adults was under investigated. Murray et al (2005) compared age-matched older adult fallers and non-fallers when standing on a compliant surface with eyes closed which requires greater use of vestibular cues. Fallers performed significantly worse, implying impaired vestibular function. Recently, vestibular dysfunction was reported for 73% of older adults reporting instability referred for multidimensional falls risk assessment (Jacobson et al. 2008). Similar proportions report symptoms indicative of a vestibular impairment (i.e. giddiness, unsteadiness) when presenting to an accident and emergency department following a fall (Pothula et al. 2004).

Vestibular dysfunction can disrupt normal functioning of vestibular ocular (VOR) and vestibulospinal reflexes. Vestibular compensation is the process by which oculo-motor, sensory and postural control recovers post-vestibular insult. However it occurs at differing rates, to differing final extents, and may remain incomplete in some patients (Curthoys and Halmagyi 1995). Deficiencies in dynamic visual acuity, a marker of VOR function, have recently been identified in older adult fallers, with the degree of impairment related to the level of impairment on complex gait tasks (Honaker and Shepard 2011). Vestibular dysfunction has also been associated with both hip and wrist fractures in older adult fallers (Kristinsdottir et al. 2000; Kristinsdottir et al. 2001; Zur 2006).

No studies to date have assessed and compared vestibular function in healthy older adults and fallers to determine whether vestibular dysfunction is increased in the latter. Also no studies have compared clinical and other characteristics of older adults referred for multidimensional balance assessment at a tertiary falls clinic or for vestibular function testing at a neuro-otology department. The purpose of this study was to 1) investigate the prevalence of vestibular dysfunction in healthy older adults and those presenting to a falls clinic for multi-factorial assessment of falls risk and 2) determine differences between healthy older adults, fallers and vestibulopathic patients with regards to subjective symptoms, activities of daily living (ADLs), balance confidence, falls risk, and functional gait assessment.

4.3 Materials and Methods

4.3.1 Subjects:

All participants were aged 65 years or older and prior to inclusion in the study, were medically screened for exclusion criteria including musculoskeletal and neurological deficits that may significantly affect postural instability; cognitive impairment was screened using an abbreviated Mental Test Score $<8/10$. Three participant groups were recruited:

- Older adult fallers (Group F) ($n=25$, mean age=76.6 (68-88 years), male=4) recruited from falls clinics within the Southwark and Lambeth Integrated Care Pathway for Fallers (London, UK). Inclusion criteria were ≥ 2 unexplained falls in the previous twelve months and no suspected vestibular pathology (including BPPV). Fallers with cardiac syncope/pre-syncope, acute illness, medication side-effects or drug intoxication were excluded.
- Healthy older adults (Group H) recruited from community exercise classes provided by Southwark Council (London, UK) ($n=16$, mean age=74.5 (65-84 years), male=3).
- Individuals with a diagnosed peripheral vestibular disorder (Group PV) ($n=15$, mean age=70.9 (65-89 years), male=7) recruited from the Department of Neuro-otology, National Hospital for Neurology and Neurosurgery (London, UK). Inclusion criteria were a $\geq 8\%$ canal paresis on Fitzgerald-Hallpike bithermal caloric testing using the optic fixation method and /or the presence of unidirectional spontaneous

vestibular nystagmus on electronystagmography (ENG). All subjects had yet to undergo vestibular rehabilitation therapy.

The local ethics committee approved the study.

4.3.2 Neuro-otologic Assessment

All subjects underwent a routine neuro-otologic examination performed by a senior audiologist to determine vestibular function. Tests included Fitzgerald-Hallpike bithermal caloric stimulation using optic fixation, and electronystagmography (ENG) to assess saccades, smooth pursuit, VOR, optokinetic nystagmus, and VOR suppression. The Dix-Hallpike test for posterior canal BPPV and Halmagyi head thrust test were also performed. Diagnosis (or exclusion) of a peripheral and/or central vestibular disorder was based upon review of the history, clinical assessment, caloric and ENG data by the attendant neuro-otologist doctor.

4.3.3 Balance and Gait Measures

Dynamic computerised posturography

The Sensory Organization Test (SOT) was performed according to published protocol (Equitest; Neurocom International, Oregon, USA) yielding an average composite equilibrium score, ranging from 0 % (no balance) to 100% (maximum stability). Scores <70% are considered abnormal (Neurocom 1999). A cut-off of 38% is predictive for multiple falls (Whitney et al. 2006).

Functional Gait Assessment (FGA) (Wrisley et al. 2004)

The FGA is validated for use in older adult fallers(Wrisley and Kumar 2010)and patients with vestibular disorders(Wrisley et al. 2004). Performance is rated between 0 (severe impairment) and 3 (normal) on tasks including walking with head movements, tandem, or backwards. Scores $\leq 22/30$ identify fall risk and predict unexplained falls in community-dwelling older adults (Wrisley and Kumar 2010)

Short-form Physiological Profile Assessment (PPA)(Lord et al. 2003)

The PPA is a validated falls risk assessment tool and predicts future falls in older adults (Lord et al. 2003). It includes five independent predictors for multiple falls: edge contrast sensitivity, knee joint proprioception, maximal isometric quadriceps strength, hand reaction time and postural sway when standing on foam with eyes open. Individual scores are standardised for age and gender and combined to compute the PPA falls risk score; positive values indicate a higher falls risk.PPA test score variability is computed by converting all raw data to z scores and determining the standard deviation. High variability indicate impairments in a specific test, whereas low variability reveals performance consistency across tests (Liston et al. 2012).

4.3.4 Questionnaires:

For Copies of all questionnaires used please see Appendix 10.

Activities-specific Balance Confidence Scale (ABC Scale) (Powell and Myers 1995)

The ABC asks patients to rate their perceived level of confidence (0%-100%) in performing 16 ADLs without losing balance. Scores of $\leq 67\%$ indicate increased falls risk (Lajoie and Gallagher 2004).

Hospital Anxiety and Depression Scale (HAD) (Zigmond and Snaith 1983)

The HAD independently assesses non-somatic symptoms of anxiety (HAD-A) and depression (HAD-D). Composite scores range between 0-21. Scores of 8-10 are borderline and those $>10/21$ indicate clinical depression or anxiety.

Situational Characteristic Questionnaire (SCQ) (Guerraz et al. 2001)

The SCQ yields a normalized score between 0 (never) to 4 (always) measuring how frequently symptoms are provoked or exacerbated in environments with visual-vestibular conflict or intense visual motion (e.g. walking down supermarket aisles). Scores $\geq 0.7/4$ indicate Space and Motion Discomfort (SMD) symptoms (Pavlou et al. 2006).

Vertigo Symptom Scale (VSS) (Yardley et al. 1992)

The VSS yields two normalized scores of symptom frequency, ranging from 0 (no symptoms) to 4 (daily symptoms), assessing vestibular symptoms (VSS-V; e.g. giddiness, imbalance) and autonomic/somatic anxiety (VSS-A; e.g. heart pounding). Scores $>0.3/4$ are indicative of vestibular pathology (Pavlou et al. 2006)

Vestibular Disorders Activities of Daily Living Scale (VDADL) (Cohen and Kimball 2000)

The VDADL, a 28-item scale, assesses the effect of balance disorders on a person's perceived ability to perform tasks in 3 domains: functional (washing/dressing), ambulation (indoor/outdoor) and instrumental (driving, chores). A normalised score (range 0-10) for each sub-scale is produced; higher numbers indicate greater impairment.

4.3.5 Falls History

Falls as defined by the Kellogg International Working Group (Kennedy and Coppard 1987) were recorded for the preceding year.

4.3.6 Statistical Analysis

Statistical analysis was performed on anonymised data using SPSS version 17 (SPSS Inc., Chicago, Ill). Differences in proportion of vestibular dysfunction between Groups F and H and gender composition between all groups were assessed using Chi-square tests. Between-group differences were assessed using Kruskal-Wallis with post-hoc Bonferroni adjusted Mann-Whitney tests.

HAD-A and, HAD-D, scores were correlated with all other collected data using Spearman Rank correlations to determine associations between psychological symptoms, falls risk and perceived function. Only significant correlations will be reported. Significant results for all tests were assumed if $p < .05$.

4.4 Results

4.4.1 Demographics

Gender did not significantly differ between-groups ($\chi^2=5.169$, 2DF, $p=.075$) but age did ($\chi^2=9.407$, 2DF, $p<.01$) with Group PV participants significantly younger than Group F ($U=76.5$, $z=-3.109$, $p<.01$).

4.4.2 Prevalence of vestibular dysfunction

Vestibular dysfunction was significantly more prevalent in older adult fallers ($\chi^2= 14.861$, 1 DF, $p<.01$), with 80% having an undiagnosed vestibular disorder. This compares to a prevalence of 18.75% in the healthy group. Diagnoses and vestibular findings are listed in

Variable	Group F (n=25)	Group PV (n=15)	Group H (n=16)
<i>Peripheral</i>			
CP >8% (+DP)	7(2)	9	0
BVH	2	4	0
DP >15%	8	1	2
Endolymphatic hydrops	0	1	0
No abnormal findings	5	0	13
<i>Central</i>			

Broken smooth pursuit and poor			
VOR suppression	1	0	1

Abbreviations: Group F = older adult fallers; Group PV= Patients with a peripheral vestibular disorder; Group H= healthy older adult participants; CP = canal paresis based on Fitzgerald - Hallpike caloric testing as measured by the duration parameter using the Jongkees formula of more than 8% in the absence of optic fixation; BVH = Bilateral vestibular hypofunction based on caloric and/or electronystagmography (ENG) findings; DP>15% = directional preponderance based on the presence of unidirectional spontaneous nystagmus on gaze testing with enhancement of the response on removal of optic fixation on ENG; VOR = vestibular ocular reflex

Table 4.1.

Variable	Group F (n=25)	Group PV (n=15)	Group H (n=16)
<i>Peripheral</i>			
CP >8% (+DP)	7(2)	9	0
BVH	2	4	0
DP >15%	8	1	2
Endolymphatic hydrops	0	1	0
No abnormal findings	5	0	13
<i>Central</i>			
Broken smooth pursuit and poor VOR suppression	1	0	1

Abbreviations: Group F = older adult fallers; Group PV= Patients with a peripheral vestibular disorder; Group H= healthy older adult participants; CP = canal paresis based on Fitzgerald - Hallpike caloric testing as measured by the duration parameter using the Jongkees formula of more than 8% in the absence of optic fixation; BVH = Bilateral vestibular hypofunction based on caloric and/or electronystagmography (ENG) findings; DP>15% = directional preponderance based on the presence of unidirectional spontaneous nystagmus on gaze testing with enhancement of the response on removal of optic fixation on ENG; VOR = vestibular ocular reflex

Table 4.1 Proportions of specific vestibular diagnoses for each subject group

4.4.3 Physical measures

Falls history ($\chi^2=36.528$, 2DF, $p<.01$), FGA ($\chi^2=18.776$, 2DF, $p<.01$), dynamic computerised posturography ($\chi^2=8.736$, 2DF, $p<.05$) and PPA ($\chi^2=16.151$, 2DF, $p<.01$) scores significantly differed between-groups. Post-hoc analysis revealed increased PPA falls risk and lower (i.e. worse) posturography scores for Group F compared to Group H ($p<.01$). Group F also had significantly worse FGA scores (PV= $p<.05$, H= $p<.01$, Figure 4.1) and reported more falls than both Groups PV and H ($p<.01$). Fallers (Group F) reported on average 3 falls within the past 12 months, whereas only two of the healthy older adults reported falling, both of whom reported a single fall. Six individuals within Group PV reported falls, four reporting multiple falls and two reporting single falls. There were no significant differences noted between Groups PV and H for reported falls.

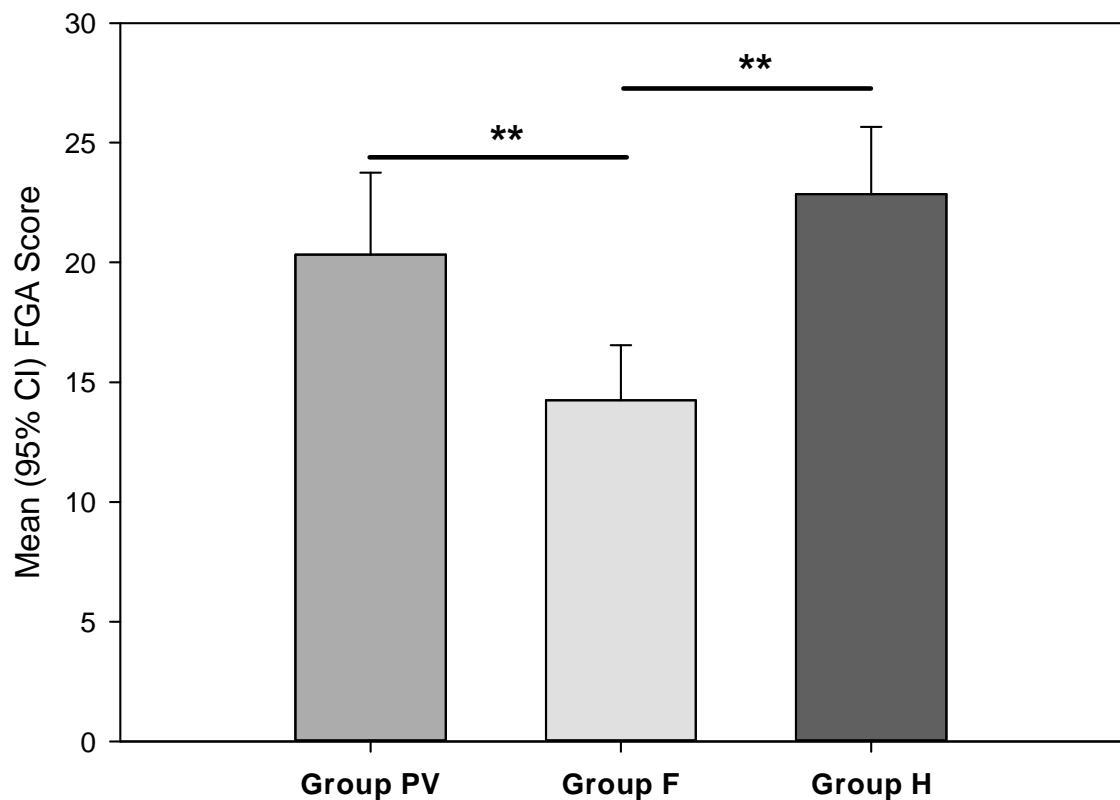


Figure 4.1 Mean (95% CI) score on the Functional Gait Assessment. ** $p < .01$

The PPA falls risk score showed only a trend towards significance between Groups PV and F ($p = .078$) (for physical measure data see Table 4.2). However, on individual PPA component tests, Group F had significantly weaker isometric quadriceps strength compared to Groups PV ($z = -3.194$, $p < .01$) and H ($z = -4.175$, $p < .01$), significantly worse edge contrast sensitivity scores compared to Group PV ($z = -2.66$, $p < .05$), and greater sway compared to Group H. Component tests showed no significant differences between Groups PV and H. No significant between-group differences were noted for PPA variability.

		Age (yrs)		Falls (n)		FGA		CDP (%)		PPA Risk	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
	F (n=25)	76.56 [*]	5.73	3 ^{**‡}	0.96	14.24 ^{**‡}	5.58	48.71 [‡]	16.58	2.64 ^{**‡}	1.29
Group	PV (n=15)	70.60	6.40	1	1.44	20.33	6.18	55.47	16.91	1.51	1.29
	H (n=16)	74.00	6.26	0	0.34	23.19	4.69	65.19	16.17	0.93	0.94

Table 4.2 Mean (SD) scores for physical measures.

^{*} Significantly different to Group PV (p<0.05), ^{**} Significantly different to Group PV (p<0.01),

[†] Significantly different to Group H (p<0.05), [‡] Significantly different to Group H (p<0.01).

4.4.4 Subjective questionnaire data

Significant between-group differences were noted for vestibular symptoms (VSS-V: $\chi^2=9.983$, 2DF, $p<.01$), autonomic anxiety (VSS-A: $\chi^2=9.705$, 2DF, $p<.01$), perceived functional performance (VDADL-F: $\chi^2=13.314$, 2DF, $p<.01$), ambulatory ability (VDADL-A: $\chi^2=9.569$, 2DF, $p<.01$), instrumental ability (VDADL-I: $\chi^2=16.065$, 2DF, $p<.01$), anxiety (HAD-A: $\chi^2=9.4$, 2DF, $p<.01$) and balance confidence (ABC: $\chi^2=15.481$, 2DF, $p<.01$). No significant between-group differences were noted for depression (HAD-D) and space and motion discomfort (SCQ) symptoms.

On post hoc-analysis, only VDADL-F scores differed significantly ($p<.05$) between Groups F and PV indicating greater impairment for the former. Interestingly, Group F did not report significantly different levels of vestibular symptoms to Group PV (Figure 4.2), further investigation of individual item responses showed a significantly higher frequency of “feeling unsteady, about to lose balance” symptoms lasting <2 minutes for Group F compared to Group PV (item 18a, $z=-2.33$, $p<.05$).

Conversely, Group F significantly differed to Group H ($p<.01$) for the VSS-V, VSS-A, VDADL-F,A, and I, ABC, and HAD-A with Group F reporting worse symptoms. No significant differences were noted between Group H and Group PV, but VSS-V scores approached significance ($p=.06$) with the latter reporting greater symptoms. Descriptive data and statistics are displayed in Table 4.3.

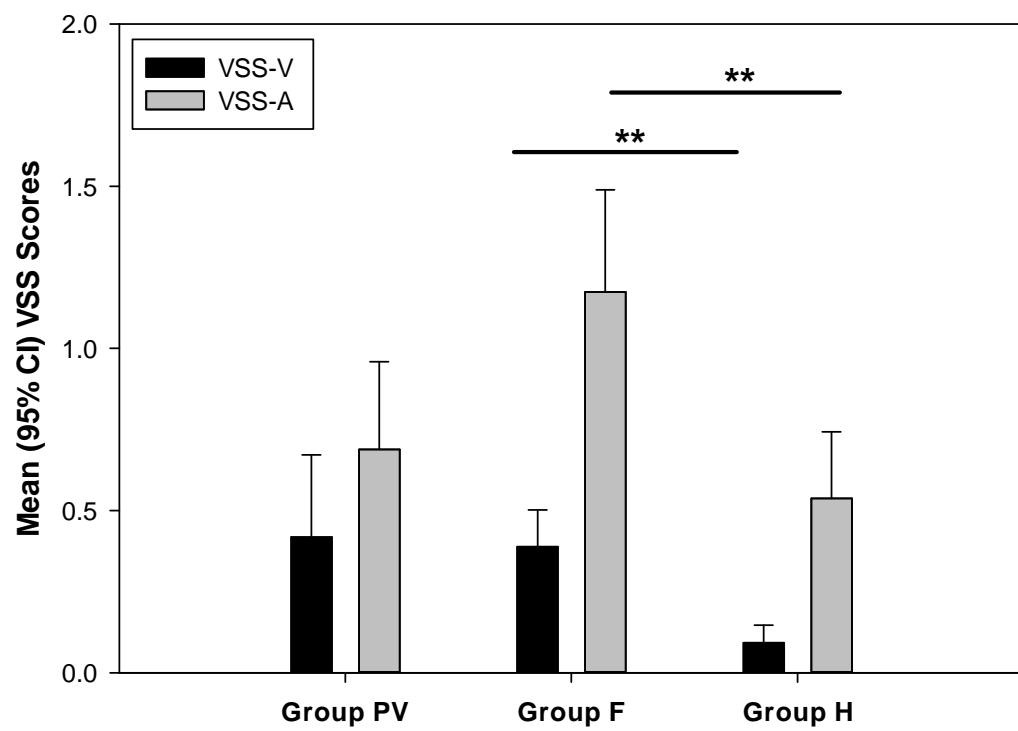


Figure 4.2 Mean (95% CI) for vestibular (VSS-V) and somatic anxiety (VSS-A) symptoms as measured by the Vertigo Symptom Scale, ** $p < .01$

	SCQ		VSS-V		VSS-A		VDADL-F		VDADL-A		VDADL-I		HAD-D		HAD-A		ABC	
Group	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
F (n=25)	0.75	0.72	0.39 [†]	0.27	1.17 [†]	0.76	2.66 ^{**†}	1.25	3.70 [†]	1.73	2.78 [†]	1.55	4.56	3.74	7.12 [†]	4.00	52.64 ^{**†}	22.14
PV (n=15)	0.98	0.97	0.42	0.46	0.69	0.49	1.75	0.84	2.74	1.93	2.43	1.79	4.93	4.22	6.13	4.19	70.04	24.22
H (n=16)	0.38	0.30	0.11	0.11	0.54	0.39	1.54	0.80	1.98	0.86	1.22	0.26	3.38	2.63	3.44	2.50	82.76	11.95

Table 4.3 Mean (SD) scores for questionnaire data

* Significantly different to Group PV ($p<0.05$), ** Significantly different to Group PV ($p<0.01$),

[†] Significantly different to Group H ($p<0.05$), [†] Significantly different to Group H ($p<0.01$).

4.4.5 Correlations

Vestibular impairment showed a significant relationship with VSS-V scores whereby participants with vestibular impairment had higher (i.e. worse) scores ($r=0.30, p<0.05$). Vestibular impairment did not correlate with other measures. There were no significant within correlates of vestibular impairment.

Both Groups PV and F showed a significant positive relationship between increased (i.e. worse) HAD-A scores and increased SCQ (PV: $r=.684, p<.01$, F: $r=.54, p<.01$) VSS-V (PV: $r=.531, p<.05$, F: $r=.645, p<.01$), and ABC (PV: $r=-.705, p<.01$, F: $r=-.574, p<.01$) scores. HAD-A also correlated with falls history ($r=.557, p<.01$) and VDADL-F ($r=.609, p<.01$) in Group F, with increased HAD-A scores associated with a greater number of reported falls and difficulty in functional ADLs. Increased depressive symptoms were positively associated with VDADL-F in both groups PV and F (PV: $r=.612, p<.05$, F: $r=.571, p<.01$). In Group PV further significant associations were noted for VDADL-A ($r=.683, p<.05$), VDADL-I ($r=.624, p<.05$), PPA ($r=.589, p<.05$) and ABC ($r=-.607, p<.05$). In Group F depressive symptoms correlated with vestibular and autonomic anxiety symptoms; VSS-V ($r=.406, p<.05$) and VSS-A ($r=.528, p<.01$). Greater depressive symptoms were associated with increased reported symptoms and reduced ADL ability.

4.5 Discussion

This study investigated vestibular function, physical function, falls risk, subjective vestibular symptoms and balance confidence between age-

matched healthy community-dwelling older adults, fallers, and individuals with a confirmed peripheral vestibular disorder. This discussion is separated into 4 sections: 1) Vestibular Function, 2) Physical measures, 3) Subjective symptoms and 4) Implications for practice.

4.5.1 Vestibular Function

Comparisons of vestibular function between healthy older adults and fallers have not previously been reported. The fallers recruited into this study had previously been assessed by a consultant geriatrician within a specialist falls service, with no vestibular pathology suspected. The present study found that 80% of fallers had clinically significant vestibular pathology, which was significantly higher than in healthy controls (18.75%). This may be a significant contributing factor to falls in this cohort. Currently vestibular function testing is not explicitly recommended in the assessment of older adult fallers (British Geriatrics Society and American Geriatrics Society 2011). Based on these and other authors' findings indicating that 70-80% of older adult fallers have reduced vestibular function (Jacobson et al. 2008; Agrawal et al. 2009) incorporating a simple vestibular screening test may significantly benefit clinical management. An example is the clinical dynamic visual acuity test (DVA), a well described, non-invasive measure of VOR function (Herdman et al. 1998)(and therefore peripheral vestibular function) which is sensitive to predicting falls risk in older adults (Honaker and Shepard 2011).

4.5.2 Physical measures

Fallers display greater impairment across physical measures and report more falls. Mean posturography scores suggested poor balance function for all groups, although Group H scores approached normal ranges. Group PV scores were similar to those previously reported for non-faller vestibular patients in previous work (Whitney et al. 2006). However, Group F displayed higher composite scores than those previously reported for vestibular patients experiencing multiple falls (Whitney et al. 2006). This may be due to participant characteristics in the previous study (younger age, single pathology) whereby a lower score would be required to indicate recurrent falls compared to an older adult faller population with manifold impairments of which sensory organisation is only one component. In fact based on Whitney et al's (Whitney et al. 2006) findings about 50% recurrent fallers would be missed by posturography alone.

Mean FGA scores indicated an increased falls risk and poorer ability to perform complex gait tasks for both patient groups as reported by others (Wrisley and Kumar 2010). This is unsurprising. It is well-established that vestibular dysfunction can increase falls risk and a growing body of evidence indicates people with vestibular disorders fall frequently (Herdman et al. 2000; Kristinsdottir et al. 2001; Whitney et al. 2002; Murray et al. 2005; Zur 2006; Jacobson et al. 2008; Agrawal et al. 2009). However, Herdman et al (Herdman et al. 2000) noted that reported falls for patients aged ≥ 65 with unilateral vestibular loss, as in the majority of patients in our study, is similar to that for age-matched healthy community-dwelling individuals. Falls history

did not differ between Groups H and PV, However Group F reported significantly more falls compared to both groups. This between-group discrepancy may be explained by PPA findings.

Although the composite PPA falls risk score's validity has been questioned due to the scoring method for the postural sway measure (Liston et al. 2012), the validity of individual component tests as independent predictors of future falls is well-established (Lord and Ward 1994; Lord and Clark 1996; Lord et al. 2003). All groups demonstrated increased falls risk based on PPA scores, with Group F having a significantly higher falls risk than Group H. Variability levels were similar between-groups, indicating relative consistency across measures, and therefore poor performance in one single test did not influence the falls risk score. Rather, a consistent decline in ability across all measures was responsible for increases in PPA falls risk. However, there were significant differences between Group F and Groups PV (Strength and Vision) and H (Strength and Sway) noted indicating that these measures were the most affected in the respective groups. Although Groups PV and F are similar in terms of vestibular dysfunction, Group F is older, weaker, has greater gait impairment and experiences multiple falls. Therefore combining treatment approaches to include lower limb strengthening, gait practise and customised vestibular rehabilitation for fallers and vestibular patients may prevent the younger, fitter Group PV from experiencing multiple falls in future.

Older adults presenting with a falls history coupled with unsteadiness and occasionally with symptoms of dizziness or giddiness may result in vestibular pathology being overlooked. Conversely, younger, fitter individuals with greater ability to perform complex gait tasks yet reporting similar levels of vestibular symptoms are referred for specific vestibular function testing. Lawson et al (Lawson et al. 2005) described similar referral patterns whereby individuals with undiagnosed benign paroxysmal benign vertigo (BPPV) were more likely to be referred to a falls service rather than a specialist ENT service if older, reported falls and dizziness of more than one aetiology e.g. BPPV, orthostatic hypotension, drug side effect (Lawson and Bamiou 2005). It is important for the high prevalence of, and atypical presentation of vestibular dysfunction in older adults to be recognised in the falls clinic setting to ensure best management and treatment.

4.5.3 Subjective Symptoms

Dizziness is one of the most frequent complaints in older adults presenting to a primary care practice (Koch and Smith 1985) and many studies focus on dizzy or vertiginous symptoms in older adults (Tinetti et al. 2000; Pothula et al. 2004; Murray et al. 2005; Agrawal et al. 2009)). Reports of dizziness or vertigo increases with advancing years (Agrawal et al. 2009), is associated with falls (Pothula et al. 2004) and a variety of domains (e.g. cardiovascular, sensory, medication) and has been postulated as a geriatric syndrome (Tinetti et al. 2000). Both Groups PV and F report similar, significant levels of vestibular symptoms, yet scores are lower (i.e. better) compared to those reported in younger people with peripheral vestibular disorders (Pavlou et al.

2004; Pavlou et al. 2006). A possible explanation for this is the primary complaint of unsteadiness and the low reporting of dizziness or other common vestibular symptoms. Only eight Group F participants reported rotatory dizziness within the past month, of which six were diagnosed with vestibular dysfunction. More interestingly, 82% of fallers reporting no dizziness were diagnosed with vestibular dysfunction. For Group F, the lower overall vestibular symptom scores, non-report of dizzy symptoms when attending the falls clinic, and predominant symptom of unsteadiness most likely contribute to the reality that vestibular dysfunction was not considered as a possible causative factor for their falls. In the United States National Audit Survey, 35.4% of individuals aged ≥ 40 had evidence of vestibular dysfunction, of which one-third also did not report dizziness (Agrawal et al. 2009). These as well as our findings highlight the need for vestibular function to be tested within the routine falls assessment for all patients and not just those clearly reporting “dizziness”.

It is well-documented individuals with balance disorders may experience increased psychological symptoms (Yardley et al. 1992), with a profound effect on fear of falling and activity participation (Bruce et al. 2002) including ADL's. Fear of falling can also alter postural responses with measurable stiffening of posture, altered centre of mass position and increased anteroposterior sway (Carpenter et al. 2006; Davis et al. 2009), having a negative impact on postural stability.

In both patient groups higher anxiety levels were associated with poorer balance confidence and an increased level of vestibular and SMD symptoms. Increased difficulty in functional ADLs though as well as a greater number of reported falls was associated with increased anxiety symptoms only for Group F. Compared to Groups H and PV, Group F participants reported significantly reduced ability to perform all ADL's especially functional activities (i.e. washing, dressing) indicating an increased level of dependence for this group. Techniques to address and reduce anxiety symptoms may prove beneficial both for postural stability, ADL participation, and mental health.

Postural stability may also be affected by an over-reliance on visual information for postural responses (i.e. visually dependent), which increases with age (Lord and Ward 1994) and is more prevalent in fallers compared to non-fallers (Lord and Webster 1990). Patients who experience SMD are visually dependent for both perception and postural responses. In patients with a peripheral vestibular disorder and SMD situations involving visual-vestibular conflict (e.g. walking down supermarket aisles) or intense visual motion (e.g. watching wide-screen movies) can provoke or exacerbate symptoms of dizziness, disorientation, and/or unsteadiness (Bronstein 1995). This has been reported to be more common in older than younger patients with vestibular dysfunction (Whitney et al. 2002). Although no significant between-group differences were noted for SMD scores, which may in part be due to the large variability in responses, there is a trend for Group F and Group PV to report a greater level of SMD. Reducing SMD symptoms by

exposure to visual motion stimuli, improves postural stability both in healthy subjects and patients with peripheral vestibular disorders (Pavlou et al. 2004; Pavlou et al. 2011) and may be beneficial to older adult fallers.

4.5.4 Implications for practice

The British Geriatrics Society & American Geriatrics Society (BGS/AGS) joint guideline for prevention of falls (British Geriatrics Society and American Geriatrics Society 2011) recommends a balance, gait and mobility assessment but does not specifically recommend vestibular function testing. Our study demonstrates that vestibular dysfunction, although present in approximately 80% of Group F, was not identified in the falls clinic setting. This suggests that current guidance may benefit from the addition of vestibular function testing, or increasing awareness of vestibular pathology when assessing older adults presenting with multiple unexplained falls.

Older adults participating in regular physical activity have greater VOR gain, symmetrical vestibular system function and greater efficiency of postural reflexes compared to older adults that do not exercise (Gauchard et al. 2003; Gauchard et al. 2004). Our healthy older cohort participated in regular exercise which may have had beneficial effects on vestibular function and falls risk, consequentially improving balance confidence and other reported measures.

The BGS/AGS recommend exercise programmes incorporating strength, balance and co-ordination training to improve postural stability, with a recent

meta analysis (Sherrington et al. 2011) recommending techniques such as movement of the centre of mass, reducing base of support and reliance on upper limb support. Current guidelines do not recommend multi-sensory rehabilitation or sensory reweighting to improve balance function, techniques currently utilised in vestibular rehabilitation programmes. Customised vestibular rehabilitation is the mainstay of treatment for patients with vestibular disorders. Approximately 50-80% of individuals completing vestibular rehabilitation achieve significant subjective symptom (including SMD), VDADL, psychological state, gait and postural stability improvements (Whitney et al. 2002; Cohen and Kimball 2003; Pavlou et al. 2004; Hall et al. 2010). Preliminary studies report multi-sensory rehabilitation protocols incorporating vestibular rehabilitation provide significant improvements in balance function in older adults indicating they may be beneficial in falls rehabilitation (Beling and Roller 2009; Hall et al. 2010; Williams et al. 2010). However, only one study was a randomised controlled trial (Hall et al. 2010) and clinical effectiveness is yet to be conclusively proven.

4.6 Conclusions

Vestibular dysfunction is significantly more prevalent in older fallers compared to healthy older adults, with fallers reporting greater anxiety and vestibular symptoms, lower balance confidence and greater impact of balance impairments on ADL's. Vestibular symptom severity did not differ between individuals referred to a falls clinic and those referred for vestibular function testing. The former are older, report more falls, have more impaired gait and exhibit reduced function across a range of physical measures.

Increased awareness of vestibular dysfunction and its presentation in fallers is necessary, including further neuro-otological investigations in older adults reporting unsteadiness and falls. Further studies investigating the clinical effectiveness of multi-sensory rehabilitation protocols are required.

Chapter 5. The effect of OTAGO exercises with and without multi-sensory rehabilitation exercise on falls risk, gait, and balance confidence in older adult fallers: A pilot randomised control trial

5.1 Abstract

Introduction: Falls are a major problem for older adults causing a number of physical and psychological problems. Multi-sensory rehabilitation programs to improve central processing and integration of sensory information are beginning to be implemented in older adults, but have not been tested in a population of fallers.

Design: Single blinded randomised control trial to test the effects of supplementing the Otago falls programme with either a multi sensory home exercise programme (Group M, n=10) or a control stretching programme (Group S, n=11).

Setting: Tertiary falls clinic, London UK.

Participants: Community-dwelling older adults experiencing >2 unexplained falls within the previous 12 months

Measurements: All participants completed the Functional Gait Assessment (FGA), Physiological Profile Assessment (PPA) rod and disc test and subjective measures for vestibular symptoms (i.e. giddiness) and balance confidence.

Results: Group M significantly improved their FGA scores ($p<.01$), reduced their multi-factorial falls risk ($p<.05$) and significantly reduced their reported vestibular symptoms ($p<.05$) indicating a reduced risk for falling. Group S only showed improvements in balance confidence ($p<.01$) but did not reduce their falls risk on any measure.

Conclusions: Customised multi-sensory rehabilitation programmes designed to improve the utilisation of vestibular cues and promote sensory reweighting provide additional benefits in gait, falls risk and vestibular symptoms to the Otago programme. These improvements are not observed in the Otago programme when combined with stretching.

5.2 Introduction

Developed nations are growing older, with the number of older adults in the US and UK predicted to rise to approximately 20% of the total population by 2030 (Centers for Disease Control and Prevention and The Merck Company Foundation 2007; Office for National Statistics 2012). Currently, 1/3 of older adults fall annually experiencing wide ranging physical and psychological consequences which can significantly affect quality of life (Scuffham et al. 2003). Falls are also a major burden on health resources, with hip fractures alone costing the UK National Health Service £2 billion to treat in 2009 (Healthcare Quality Improvement Partnership 2011), and US Medicare \$1.9 billion in 1991 (Centers for Disease Control and Prevention 1996).

The American Geriatric Society / British Geriatric Society (AGS / BGS) joint guidelines recommend older adult fallers should receive a gait assessment and appropriate interventions targeted at improving gait and reducing falls risk (American Geriatrics Society and British Geriatrics Society 2010). The Otago programme is commonly used as it provides progressive strength, balance and gait training and can reduce falls rate by 30-40% in older adults (Campbell et al. 1997; Robertson et al. 2001; Robertson et al. 2001). However, gait and postural control are complex tasks which also require central processing and integration of visual, vestibular and somatosensory information (Horak 2006), factors not explicitly addressed by the Otago programme.

Multi-sensory rehabilitation of adults with balance disorders typically utilises techniques to improve central processing and integration of sensory information (Whitney and Sparto 2011) and has been demonstrated to be beneficial in older adults with dizziness and unsteadiness (Whitney et al. 2002; Jung et al. 2009; Hall et al. 2010), providing improvements in balance confidence and falls risk. However, at present these protocols are not commonly used, nor included in the recommendations for the rehabilitation of older adults experiencing multiple falls (American Geriatrics Society and British Geriatrics Society 2010). Recently, the effects of providing multi-sensory rehabilitation programmes to healthy community dwelling older adults have begun to be investigated with improvements in postural stability, gait, strength and functional reach compared to individuals following their usual daily routine, indicating a reduced falls risk in the active intervention group (Beling and Roller 2009; Yang et al. 2012). However, neither study provided a control group for comparison, nor were customised multisensory rehabilitation programs utilized, and in one study the multisensory exercises provided were not described (Yang et al. 2012). No studies to date have investigated providing multi-sensory training to older adult fallers, but two studies have demonstrated beneficial effects of exercise classes including an element of vestibular training in healthy community-dwelling older adults (Beling and Roller 2009; Yang et al. 2012).

A new falls rehabilitation program designed to improve strength, utilize sensory cues (or promote sensory organization), reduce space and motion discomfort and improve gait and postural control would provide a multi-

sensory rehabilitation of fallers. Therefore the aim of this pilot study is to provide a sample size calculation for a fully powered study, to investigate any possible SAE's and to determine the effectiveness of the proposed outcome measures. The primary outcome measure to determine the sample size calculation will be the change in Functional Gait Assessment between weeks 0 and 8. A secondary aim is to investigate the effects of an 8-week multi-sensory rehabilitation program on complex gait, balance confidence and falls risk in older adults experiencing multiple unexplained falls.

5.3 Material and Methods

5.3.1 Participants

Individuals were recruited between 2010- 2011 from two falls clinics within the Southwark and Lambeth Integrated Care Pathway for Fallers (London, UK). Inclusion criteria included: a) aged ≥ 65 years, b) ≥ 2 unexplained falls in the previous twelve months; c) no previous history of vestibular pathology and d) recommended to attend supervised OTAGO exercise classes. Fallers with evident cardiac syncope/pre-syncope, acute illness, medication side-effects or drug intoxication were excluded alongside those with obvious musculo-skeletal or neurologic deficits (i.e. post polio syndrome or stroke) significantly affecting postural stability and considered responsible for falls by the attending physician.

5.3.2 Allocation

The flow of participants through this randomized, blinded, parallel-group pilot study is summarized in Figure 5.1. Subjects simultaneously participated in group exercises classes and were randomly assigned to an 8-week supervised home exercise program (HEP) practicing either a generic active range of movement stretching program (Group S) or a customized multi-sensory balance rehabilitation program (Group M). An online random number generator was used to allocate patients by an independent person. All assessments were completed by a rater blinded to intervention group; participants were informed of group allocation after completing the baseline assessment. Local ethics committee approval was obtained.

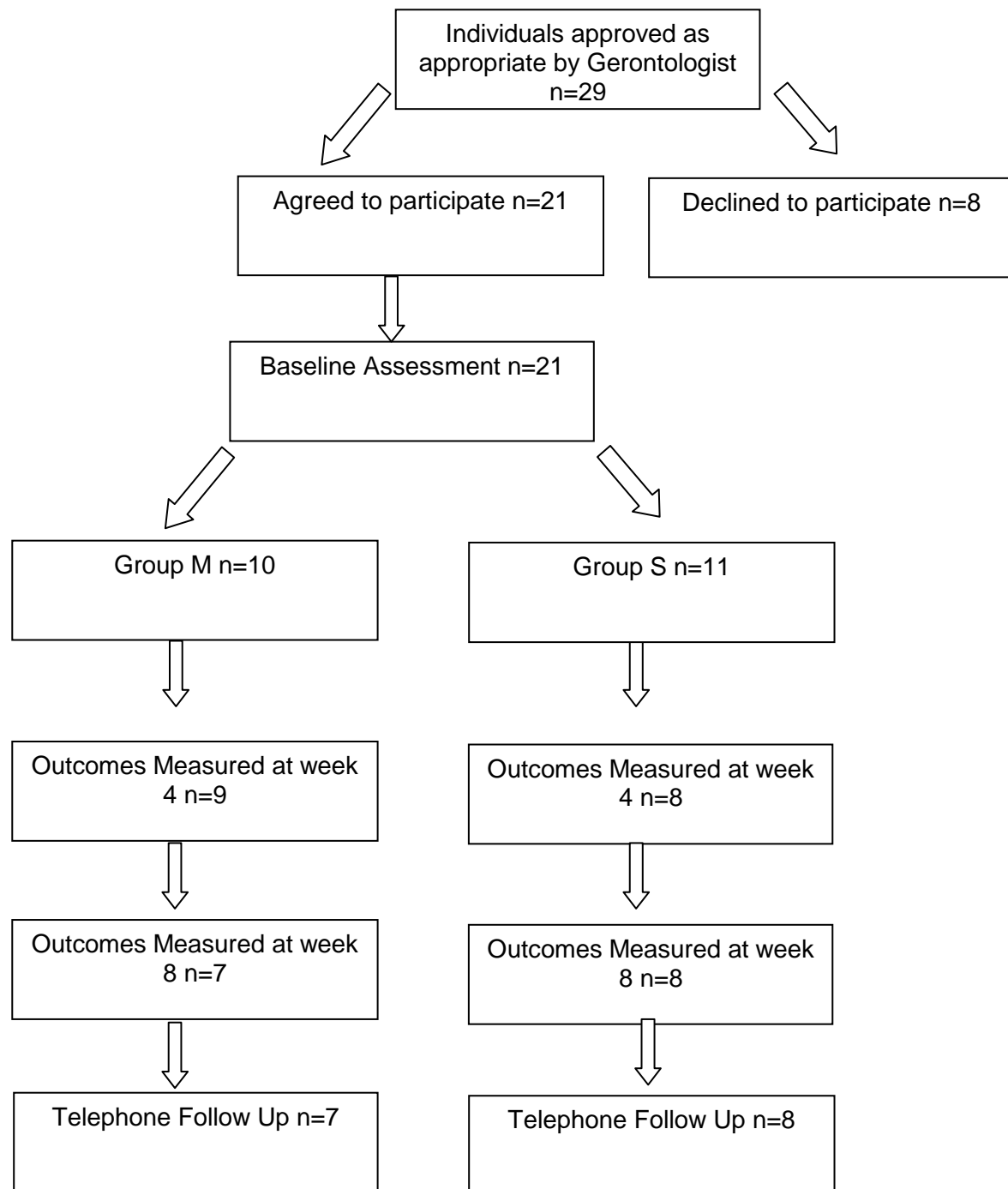


Figure 5.1 Flow chart of participants through the trial

5.3.3 Intervention

Each participant undertook an 8 week programme consisting of twice weekly group exercise classes and home therapy sessions, each lasting for 1 hour. Therefore each participant received 4x1 hour sessions per week with the physical therapist. Participants were randomised into one of two home exercise programme consisting of either i) the control intervention (Group C) which received stretches or ii) the active intervention (Group M) which received customised multi-sensory rehabilitation.

5.3.3.1 OTAGO group exercise classes:

The classes included strengthening and balance exercises based on the OTAGO program. Program details are available on the supplier's web site (<http://www.acc.co.nz>). Please see appendix 9 for a list of the Otago programme exercises. On average, each class consisted of three participants.

5.3.3.2 Home exercise program

Participants were randomised into either Group C or Group M to receive the supplementary home exercise programme which would contain stretches (Group C – Control group) or multi-sensory rehabilitation (Group M – Intervention group). Each participant received a personalised HEP consisting of 4-5 exercises to be practised twice daily. Exercises were provided via a worksheet with a diagram and written explanation and participants were instructed on performance by the physical therapist.

5.3.3.3 Stretching program (Group C)

At each home exercise session, an active range of motion stretching program was performed in sitting addressing specific reported limitations in range of motion first. Stretches included: ankle inversion/eversion and plantar/dorsi-flexion and shoulder flexion/extension, scapular setting and rhomboid stretches. Stretches for gastrocnemius and soleus were performed in standing whilst leaning against a wall. These exercises were not intended to provide any balance practise, and as such were provided as a control intervention. For an example of the home exercise programme please see appendix 11.

5.3.3.4 Multisensory balance rehabilitation (Group M)

At each home exercise session patients practised customised exercises based on individual functional deficits (neuromuscular, musculoskeletal, eye-head coordination). Specific exercises to improve postural re-alignment and movement strategies, re-train sensory strategies (i.e. reduce an over-reliance on visual cues for balance), learn to adapt strategies to changing contexts (reduced support base, upper limb activities) and vestibular exercises with and without a striped (horizontal or vertical) background were included as appropriate. Sample exercises for each are included in Table 5.1. At each session, progress was assessed, any concerns discussed, exercises not yet included in the home program were practised, and exercises were modified to gradually increase task difficulty (i.e. reduced base of support, compliant surfaces, increased head movement and/or walking speed). For an example

of the multisensory exercise programme and progressions please see appendix 11.

Seated / standing with head movements	Horizontal with fixation	Eyes open	
	Vertical with fixation	Eyes open	
	Horizontal without fixation	Eyes open / closed	
	Vertical without fixation	Eyes open / closed	
	“V” without fixation	Eyes open / closed	
	Turn to look over shoulders	Eyes open / closed	
		Eyes open / closed	
Standing	Normal BOS	Eyes open / closed	+ / - Cushion
	Reduced BOS	Eyes open / closed	+ / - Cushion
	Tandem	Eyes open / closed	
Anterior – Posterior Limits of stability	Normal BOS	Eyes open / closed	+ / - Cushion
	Reduced BOS	Eyes open / closed	+ / - Cushion
Dynamic movements	Reaching high to low	Eyes open	+ / - Cushion
	Reaching left to right	Eyes open	+ / - Cushion
	Reaching diagonally	Eyes open	+ / - Cushion
	Half steps	Eyes open	
Slow marching on the spot	Low knee lift	Eyes open	+ / - Cushion
	High Knee lift	Eyes open	+ / - Cushion
Gait forwards and backwards ± head movements	No head movement	Eyes open / closed	
	Horizontal with fixation	Eyes open	
	Vertical with fixation	Eyes open	
	Horizontal without fixation	Eyes open	
	Vertical without fixation		

Table 5.1 Summary of exercises used for Multi-Sensory Home Exercise Programme (Group M only)

5.3.4 Outcome measures

All outcome measures were assessed at baseline, 4 and 8 weeks (end of treatment). A telephone follow-up was conducted to record self-reported falls at 6 months following program completion.

5.3.4.1 Balance and Gait Measures

Functional Gait Assessment (FGA) (Wrisley et al. 2004)

The FGA, which rates performance on ten tasks including normal gait speed, turning, walking with head turns and tandem gait was the primary outcome measure. Each item is rated between 0 (severe impairment) – 3 (normal) with a maximum score of 30. A cut-off score of 22/30 has 100% sensitivity and 72% specificity to predict falls in older adults (Wrisley and Kumar 2010) with a change of ≥ 6 considered clinically significant (Alsalaheen et al. 2010)

Short-form Physiological Profile Assessment (PPA) (Lord et al. 2003)

The PPA is a validated falls risk assessment tool for use in older adults and predicts future falls with 75% sensitivity and specificity (Lord et al. 2003). The PPA comprises five measures, each an independent predictor for falls including knee joint proprioception, maximal isometric quadriceps strength and postural sway on a compliant surface with eyes open. The on-line Fallscreen program provides Z-scores for each measure and a composite PPA falls risk score, with higher values indicating poorer performance and higher falls risk. Within the PPA reported falls for the previous 12 months is also collected. Raw data for each measure and variability across measures

(Liston et al. 2012) were assessed alongside composite PPA falls risk scores.

Subjective Visual Vertical (SVV)

SVV assesses visual dependency (i.e. an over reliance on visual cues) at a perceptual level (Guerraz et al. 2001) and was assessed using a computerised version of the rod and disc test (Guerraz et al. 2001). Participants sat upright 80cm, eye levelled, from the television screen (109cm diagonally from corner to corner). A chin rest secured head position. Before each trial, subjects closed their eyes and the rod was tilted $\pm 20^\circ$, in counter-balanced order, randomized between subjects for each test condition. Subjects then adjusted the rod to their perceived gravitational vertical in their own time by rolling the wheel on a computer mouse. Rod settings without disc rotation were completed first, followed by the rotating disc ($\pm 30^\circ$ s) settings. Four trials were completed for each condition.

A custom-designed software program recorded SVV values, taken as the angular deviations from true gravitational vertical (0°) measured in degrees. Tilt of the rod's top to the subject's right or left was indicated as a positive or negative value, respectively. Each subject's average SVV value with the disc stationary served as a baseline for values obtained with the rotating disc. Each subject's average SVV value with the disc stationary served as a baseline for values obtained with the rotating disc.

5.3.4.2 Questionnaires

All participants completed validated questionnaires regarding symptoms, symptom triggers, and psychological state during the previous month, which included:

The Activities-specific Balance Confidence Scale (ABC) (Powell and Myers 1995).

The ABC assesses patients' perceived level of confidence (0%-100%) in their ability to perform 16 activities of daily living (ADL's; e.g. indoor and outdoor walking activities, reaching-oriented activities) without falling. A cut-off score of 67% has 84% sensitivity and 87% specificity for identifying falls in community-dwelling older adults (Lajoie and Gallagher 2004).

The Hospital Anxiety and Depression Scale (HAD) (Zigmond and Snaith 1983)

The HAD independently assesses non-somatic symptoms of anxiety (HAD-A) and depression (HAD-D). Composite scores range between 0-21. Scores between 8-10 are borderline values and those above 10 indicate clinical depression or anxiety.

The Situational Characteristic Questionnaire (SCQ) (Guerraz et al. 2001)

The SCQ yields a normalized score between 0 (never) to 4 (always) and measures how frequently symptoms are provoked or exacerbated in environments with visual-vestibular conflict or intense visual motion (e.g. walking down a supermarket aisle, watching moving television scenes).

Scores $\geq 0.7/4$ are indicative of space and motion discomfort (SMD) symptoms (Pavlou et al. 2006).

The Vertigo Symptom Scale (VSS) (Yardley et al. 1992)

The VSS yields two normalized scores of symptom frequency, ranging from 0 (never) to 4 (daily), assessing common vestibular symptoms (VSS-V; e.g. giddiness, unsteadiness) and autonomic/somatic anxiety (VSS-A; e.g. heart pounding). Scores of ≥ 0.3 are considered abnormal (Pavlou et al. 2006).

5.3.5 Statistical analysis

SPSS version 17 (SPSS Inc. Chicago, Ill) was used for statistical analysis. Data are reported as mean \pm SD. Between-group differences in gender composition were determined using a Chi-Squared test. Mann-Whitney tests were used to assess between-group differences at baseline and in change in measures at mid-point and completion. Friedman's ANOVAs were employed to analyse within-group changes over time with post-hoc Wilcoxon Signed Rank tests performed to investigate differences between scores collected at baseline and week eight. Pearson's rho ($r = \frac{Z}{\sqrt{N}}$) was calculated to determine effect size of the changes (Field 2005). Spearman's rho (r_s) correlations investigated associations between a) physical measures (age, falls history, FGA, PPA, SVV) and all questionnaire data, and b) HAD anxiety and depression scores with questionnaire data for i) baseline and ii) pre-post treatment change scores. Significance for all tests was assumed if $p < .05$.

5.4 Results

Statistical analysis of baseline data (Table 5.2) for all subjects (n=21) showed no significant differences between treatment groups. However a sub-analysis of individual PPA components showed significantly weaker quadriceps strength for Group S compared to Group M ($U(2)=23.5$, $p<.05$, $r=-0.49$) with no other between-group differences noted for component tests or variability.

When comparing study non-completers (n=6) and completers (n=15), the former had significantly higher PPA falls risk ($U(2) =11$, $p<.01$, $r=-0.58$) but did not differ on any other collected measure.

	Group M n=10	Group S n=11
Age	77.8 (6.1)	76.7 (5.4)
Falls	3.18 (0.98)	3.30 (0.82)
FGA	14.09 (5.89)	14.50 (4.74)
PPA	2.06 (1.64)	1.77 (0.77)
SVV	5.1 (3.0)	7.1 (2.1)
HAD-A	6.09 (3.36)	7.1 (4.93)
HAD-D	3.73 (2.53)	4.5 (2.27)
ABC	63.97 (23.69)	45.7 (28.31)
SCQ	0.41 (0.31)	0.63 (0.88)
VSS-V	0.36 (0.25)	0.36 (0.25)
VSS-A	1.24 (0.71)	1.03 (0.57)

Table 5.2 Mean (SD) values for baseline data collected for all recruits

5.4.1 Assessment at Week 4

Significant between-group differences were observed for change in FGA scores ($U(2) = 8.5$, $p < .01$, $r = -0.65$: Group M 9/9 participants improved; Group S 5/8), with Group M showing greater change (i.e. improvement) than Group S. No significant between-group differences were noted for any other measures.

5.4.2 Final Assessment

5.4.3 Between Group Differences

Mean scores for physical and self report measures are displayed in (Table 5.3 and Table 5.4). Significant between-group differences were noted for pre-post treatment change in FGA ($U(2) = 4.5$, $p < .01$, $r = -0.71$: M=7/7, S=5/8) and PPA falls risk scores ($U(2) = 10$, $p < .05$, $r = -0.54$: M=7/7, S=5/8) with Group M displaying significantly greater improvement than Group S. There is a trend for Group M to show greater improvement in VSS-V ($U(2) = 13$, $p = .081$, $r = -0.45$: M=7/7, S=4/8) and SCQ ($U(2) = 12.5$, $p = .072$, $r = -0.46$: M=5/7, S=2/8). No significant between-group differences were noted for SVV (M=6/7, S=5/8), ABC (M=6/7, S=8/8), HAD-A (M=5/7, S=3/8), HAD-D (M=4/7, S=4/8), VSS-A (M=6/7, S=4/8) and PPA component tests and variability

	Otago + Multi-Sensory Rehab			Otago + Stretching		
	Baseline (n=9)	Week 4 (n=9)	Week 8 (n=7)	Baseline (n=8)	Week 4 (n=8)	Week 8 (n=8)
FGA	15.33 (5.81)	19.78 (6.5)	22.43 (6.29)	14.13 (4.85)	15.13 (3.6)	16.13 (5.25)
PPA	1.75 (1.62)	0.97 (1.16)	0.01 (0.92)	1.67 (0.76)	1.79 (0.83)	1.42 (0.97)
SVV	4.43 (2.29)	3.64 (1.97)	2.86 (2.15)	6.98 (2.2)	6.8 (3.23)	5.72 (2.2)

	Otago + Multi-Sensory Rehab		Otago + Stretching	
	Change at week 4 (n=9)	Change at week 8 (n=7)	Change at week 4 (n=8)	Change at week 8 (n=8)
FGA	4.44 (2.19) **	6.71 (1.8) **	1.0 (2.62)	2 (3.12)
PPA	-0.78 (1.33)	-1.12 (0.73) *	0.12 (0.96)	-0.25 (0.79)
SVV	-0.78 (1.32)	-1.36 (1.53)	-1.68 (4.18)	-1.27 (2.36)

Table 5.3 Mean (SD) scores for physical outcome measure. (Presented data is from individuals that completed at least 4 weeks of the programme.) **/* p<.01/.05

	Otago + Multi-Sensory Rehab			Otago + Stretching		
	Baseline (n=9)	Week 4 (n=9)	Week 8 (n=7)	Baseline (n=8)	Week 4 (n=8)	Week 8 (n=8)
HAD-A	5.44 (3.36)	4.22 (3.63)	4.71 (4.5)	6.88 (5.54)	5 (5.5)	6.88 (6.15)
HAD-D	3.67 (2.4)	2.89 (2.67)	2.57 (2.37)	4.25 (2.49)	3.63 (2.92)	3.75 (2.76)
ABC	65.33 (26.1)	68.68 (24.01)	72.87 (26.31)	43.12 (29.05)	53.64 (28.83)	59.26 (29.54)
SCQ	0.33 (0.27)	0.37 (0.27)	0.3 (0.31)	0.42 (0.46)	0.74 (0.76)	1.11 (1.14)
VSS-V	0.28 (0.19)	0.23 (0.21)	0.15 (0.2)	0.36 (0.26)	0.28 (0.17)	0.33 (0.25)
VSS-A	1.11 (0.73)	0.84 (0.7)	0.76 (0.82)	0.93 (0.58)	0.94 (0.71)	0.82 (0.66)

	Otago + Multi-Sensory Rehab		Otago + Stretching	
	Change at week 4 (n=9)	Change at week 8 (n=7)	Change at week 4 (n=8)	Change at week 8 (n=8)
HAD-A	-1.22 (1.56)	-1.14 (1.57)	-1.88 (4.52)	0 (4.07)
HAD-D	-0.78 (1.79)	-0.86 (1.35)	-0.63 (2.13)	-0.5 (2.14)
ABC	3.34 (8.82)	11.32 (12.27)	10.52 (8.68)	16.14 (13.02)
SCQ	0.03 (0.29)	-0.04 (0.38)	0.33 (0.72)	0.7 (0.96)
VSS-V	-0.05 (0.18)	-0.19 (0.13)	-0.08 (0.15)	-0.04 (0.14)
VSS-A	-0.27 (0.46)	-0.38 (0.36)	0.02 (0.29)	-0.11 (0.4)

Table 5.4 Mean (SD) for questionnaire data. (Presented data is from individuals that completed at least 4 weeks of the programme.) **/* p<.01/.05.

5.4.4 Within Group Differences

Significant within-group improvements were noted for Group M for FGA ($\chi^2 (2) = 13.556, p < .01$) (Figure 5.2), PPA falls risk ($\chi^2 (2) = 8.00, p < .05$) (Figure 5.3), and VSS-V ($\chi^2 (2) = 8.615, p < .05$) (Figure 5.4) scores. Post-hoc analysis revealed an identical significant effect size (r) for each measure ($T = 0, p < .05, r = -0.63$). Individual PPA component tests only showed a significant reduction (i.e. improvement) in postural sway ($\chi^2 (2) = 6.077, p < .05, T = 0, p < .05, r = -0.83$). There was a trend for improvement in SVV scores: $\chi^2 (2) = 5.407, p = .07$, balance confidence (ABC Scale: $\chi^2 (2) = 5.407, p = .067$) and somatic anxiety (VSS-A: $\chi^2 (2) = 5.429, p = .066$).

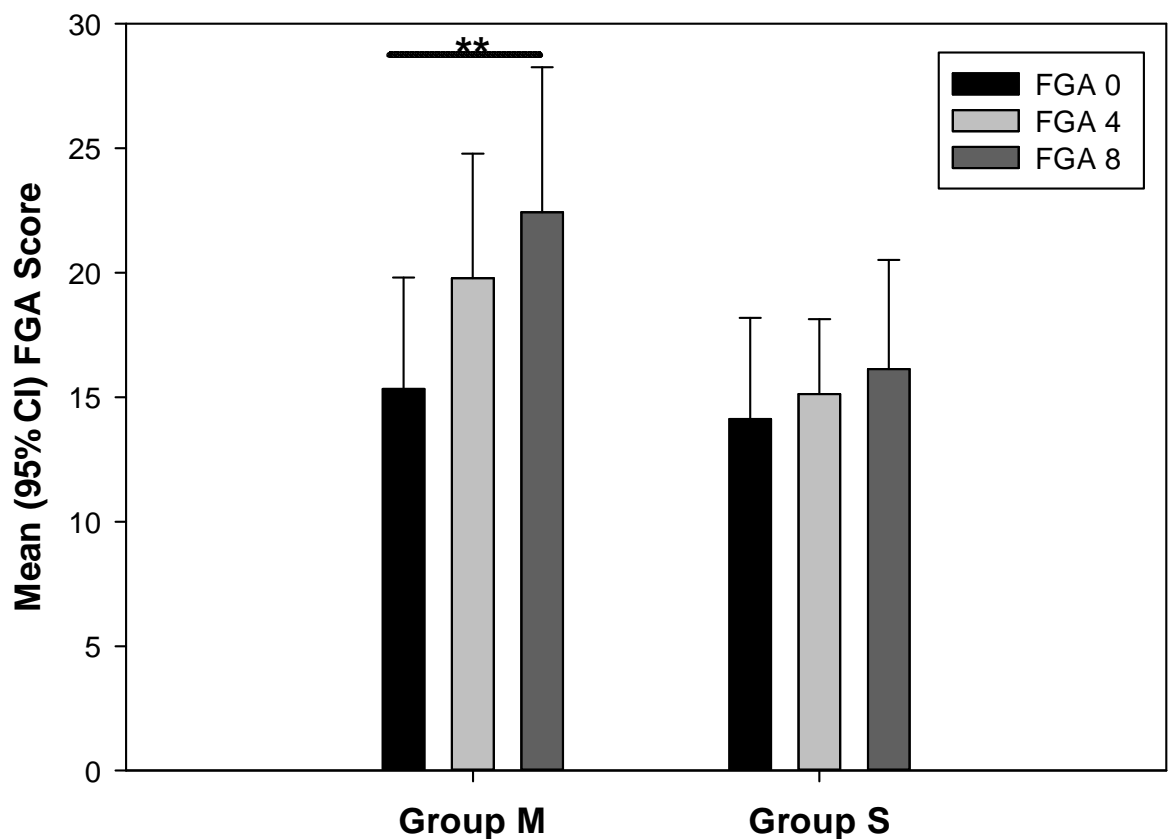


Figure 5.2 Mean Functional Gait Assessment (95% CI) scores at baseline, week 4 and week 8. **

$p < .01$

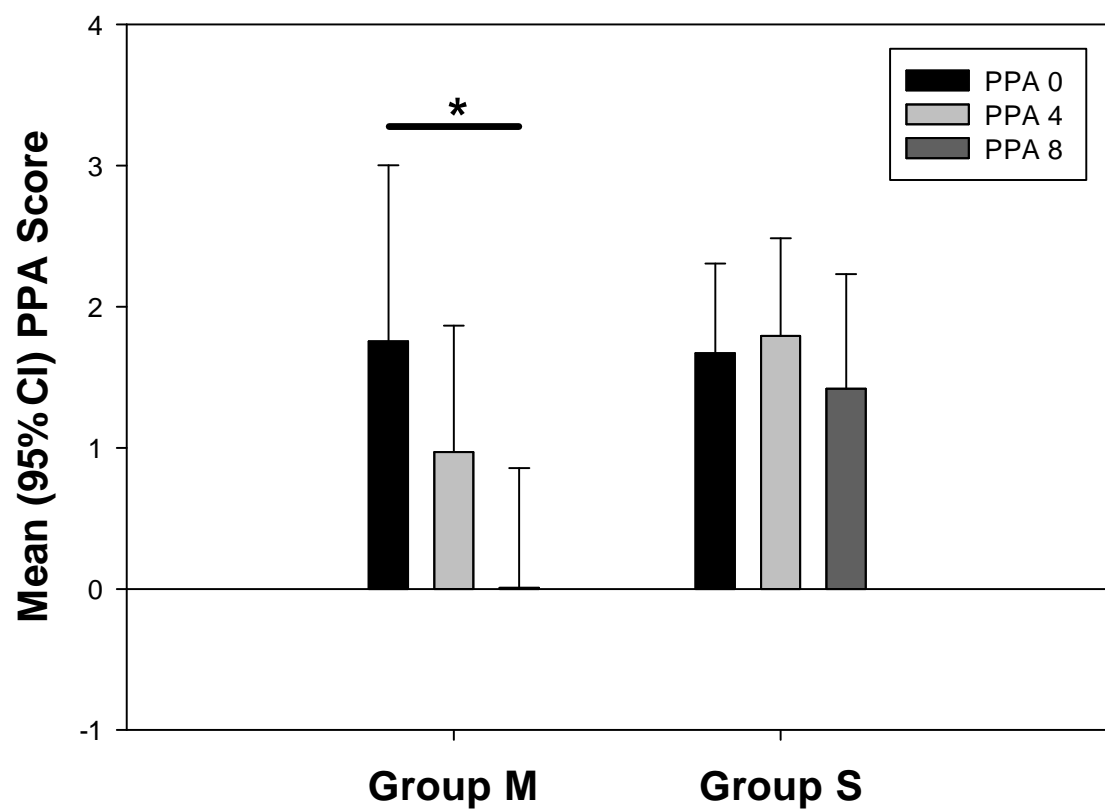


Figure 5.3 Mean (95% CI) for Physiological Profile Assessment Scores at baseline, week 4 and week

8. * $p < .05$

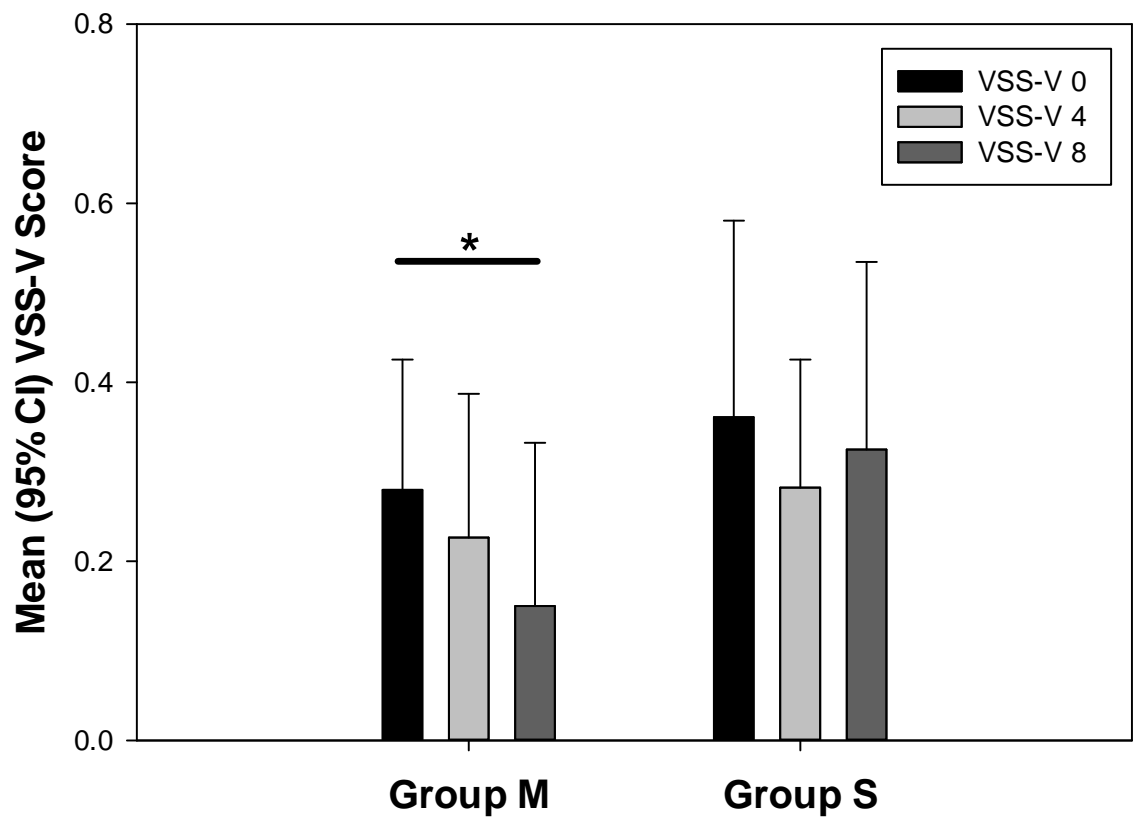


Figure 5.4 Mean (95% CI) scores for Vertigo Symptom Scale Vestibular subscale at baseline, week 4 and week 8. * $p < .05$

Group S only displayed significant within-group improvements in balance confidence (ABC scale: $\chi^2 (2) = 10.516$, $p < .01$) (Figure 5.5) with a measured effect size of -0.63 ($T = 0$, $p < .05$, $r = -0.63$). On component PPA measures a significant improvement in quadriceps strength was noted ($\chi^2 (2) = 6.645$, $p < .05$, $T = 1$, $p < .05$, $r = -0.85$).

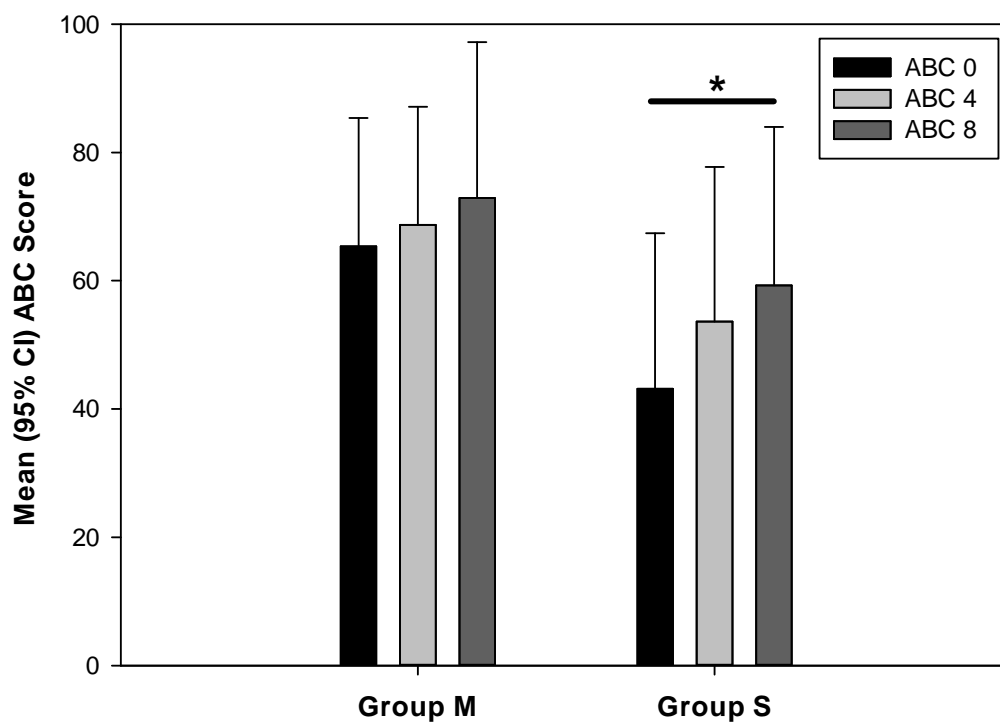


Figure 5.5 Mean (95% CI) for Activities Specific Balance Confidence Scale scores at baseline, week 4 and week 8. * $p < .05$

5.4.5 Correlation Analysis

When collapsing all patients' scores independent of group; at baseline, an increased number of falls within the past 12 months was associated with worse FGA scores ($r_s = -.463$, $p < .05$) and balance confidence ($r_s = -.589$, $p < .01$), and greater anxiety ($r_s = .710$, $p < .01$), depression ($r_s = .555$, $p < .01$), vestibular symptoms ($r_s = .614$, $p < .01$) and somatic anxiety ($r_s = .639$, $p < .01$). Poor FGA performance was associated with increased PPA falls risk ($r_s = -.464$, $p < .05$), anxiety ($r_s = -.512$, $p < .05$), and vestibular symptoms ($r_s = -.613$, $p < .01$), and reduced balance confidence ($r_s = .637$, $p < .01$). Age did not correlate with any measure at baseline. At week 8 the only significant association was between change in FGA and change in VSS-V ($r_s = -.787$, $p < .01$), with greater reductions in vestibular symptoms associated with improved FGA performance, this correlation is significant when splitting groups also (Group M: $r_s = -.764$, $p < .01$, Group S $r_s = -.841$, $p < .01$)

5.4.6 Reported falls during study and at 6-month follow-up

Three individuals from each group reported falls during the 8-weeks of therapy. For each group two individuals reported a single fall while a further participant in each group reported two falls (Group S) or four falls (Group M). At the 6 month telephone follow-up, one participant from Group M reported two falls. Two Group S participants reported 2 and 3 falls respectively. There were no significant between-group differences in reported falls either during the study or at follow up ($p = .867$ and $p = .694$ respectively).

5.4.7 Participation and drop-out

The drop-out rate was 27.3% for Group S (recurrent foot injury = 1; personal reasons = 2) and 30% for Group M (hospitalization following acute illness=1; personal reason=1; unscheduled extensive holiday =1). One Group M and all Group S drop-outs occurred prior to the Week 4 assessment.

5.4.8 Serious Adverse Events

No serious adverse events were reported through-out the duration of the trial. Two adverse events were documented which were withdrawal due to recurrent foot injury and hospitalisation following acute illness.

5.4.9 Power Calculation for Future Study

The change in FGA was used to form a power calculation using Gpower version 3.0.10 (University of Kiel). A mean FGA change of 6.5 with a standard deviation of 2.0 for Group M and a mean FGA change of 2.0 (SD 2.0) provided a sample size estimate of 8 per group. This provided 95% power with an alpha of 0.05 and an effect size of 1.77.

5.5 Discussion

This study investigated the effects of combining the OTAGO exercise program with either a multi-sensory intervention (Group M) or a control stretching program (Group S) on complex gait, falls risk, vestibular symptoms and balance confidence in age-matched older adult fallers. The supplementary exercises were tolerated well by both groups, and although drop-out rates were quite high (28%) they are similar for both groups and compare to those noted in other work (Beling and Roller 2009; Yang et al.

2012). The discussion will be divided into four sections to discuss the findings from this pilot study: 1) Physical measures, 2) Visual measures, 3) Subjective measures and 4) Implications for practice.

5.5.1 Physical measures

Only Group M who received the OTAGO program plus supervised multisensory balance rehabilitation achieved significant FGA improvements. Outcome measures able to detect clinically significant changes over time are necessary in determining an intervention's efficacy (Guyatt et al. 1987). Although the minimal clinically significant change has not been established for the FGA, Alsalaheen et al (2010) (Alsalaheen et al. 2010) report it as an average 6 point improvement based on clinical experience. Group M achieved a mean change of greater than 6 points with all patients improving and post-intervention scores equal to the cut-off for classifying falls risk and predicting unexplained falls in community-dwelling older adults (Wrisley and Kumar 2010). In contrast, final FGA scores for Group S continued to indicate an elevated falls risk with approximately 38% (3/8) of patients showing no improvement. Albeit this is a pilot study, these findings must not be ignored considering the implications of post-intervention FGA scores for Group S.

Reduced gait speed is associated with reduced capacity in functional activities from dressing to community ambulation (Whitney et al. 2004; Verghese et al. 2011). The FGA includes timed walking at speeds required to safely cross a street (0.5m/s (Robinett and Vondran 1988)) and many tasks necessary for functional mobility (Wrisley and Kumar 2010) Group S's post-

intervention FGA score indicates that gait speed and performance on tasks such as walking with head movements, remains impaired.

These findings are not unexpected. Postural control and spatial orientation are interlinked and emerge from an interaction of many musculoskeletal and neural systems. Effective postural control relies on numerous properties including peripheral sensory input, sensory re-weighting, promoting adaptation to changing environmental and task conditions, and additional higher order balance mechanisms including anticipatory postural adjustments. The balance component of the OTAGO program does not specifically aim to improve postural alignment, movement, sensory strategies, adaptation to changing contexts or vestibular function and although proven to reduce falls in older adults (Campbell et al. 1997; Robertson et al. 2001; Robertson et al. 2001), it is more effective for frail older fallers aged 80 years and above (Campbell et al. 1999). Our participants were active younger community-dwelling older adults with a mean age of 77. Therefore previous, together with current findings appear to suggest that younger, active older adults require a more comprehensive balance rehabilitation program in order to achieve significant improvements with regards to functional mobility and complex gait.

With regards to FGA improvements in Group M, the specific role of vestibular exercises should be considered. The FGA is not only sensitive to predicting falls in older adults but also has concurrent validity with measures sensitive to predicting the impact of vestibular dysfunction on complex gait tasks

(Wrisley et al. 2004; Wrisley and Kumar 2010). The magnitude of FGA score improvements in Group M may be due to improved utilisation of vestibular cues, which is supported by significantly reduced vestibular symptoms in this group. Previous studies based in the United Kingdom and United States with similar case-mix (Liston et al. 2011) identified that approximately 80% of individuals experiencing multiple unexplained falls have significant clinical vestibular dysfunction (Jacobson et al. 2008; Agrawal et al. 2009), supporting our rationale for providing multi-sensory training to individuals experiencing multiple unexplained falls. In studies investigating the efficacy of vestibular rehabilitation in older adults with dizziness or confirmed vestibular pathology no negative effect of age has been reported, highlighting the potential use of this type of intervention in older adult fallers reporting unsteadiness (Whitney et al. 2002; Cohen and Kimball 2003; Cohen and Kimball 2004).

However, improved use of vestibular cues cannot be the only cause for improvement. Multi-dimensional falls risk as measured by the PPA which does not include a vestibular component, was also significantly reduced post-intervention to well within normal ranges (Lord et al. 2003) for Group M, but not for Group S whose scores continued to indicate moderate falls risk. Findings for Group S are similar to previous findings showing no change in PPA falls risk following completion of the OTAGO program (Liu-Ambrose et al. 2008). Liu-Ambrose et al (2008) suggested that in frail older adults (as included in their study), a lower percentage change in the PPA falls risk score may be needed to detect a clinically meaningful change. However increased frailty in Group S cannot be a contributing factor to our findings as

both groups performed similarly at baseline not only for the PPA but on all outcome measures. The improved PPA falls risk score in Group M occurred primarily through improvements in postural sway brought about by the multi-sensory rehabilitation regime. However, non-significant improvements in other component measures may have contributed to the reduction in PPA falls risk as PPA variability did not change. It is important to note that quadriceps strength improvements in isolation in Group S did not link to a decrease in PPA falls risk. Previous studies have shown improvements in PPA falls risk with strength training (Liu-Ambrose et al. 2004; Lord et al. 2005), however our intervention may not have been of sufficient duration to provide appreciable significant change in PPA falls risk due to strengthening alone. Improvements in PPA falls risk following strength training are not associated with improvements in gait or a reduction in falls (Liu-Ambrose et al. 2004; Lord et al. 2005), this lack of change in gait function is also observed in Group S for FGA.

The customised balance exercises practised in this study were more complex than exercises routinely provided for fallers (Campbell et al. 1997; Robertson et al. 2001) yet participants were able to tolerate them with a drop-out rate similar to that noted in previous studies (Yang et al. 2012) and no difference between Groups M and S. Although larger studies are required to substantiate findings, only Group M receiving multi-sensory rehabilitation achieved significant improvements in complex gait and multi-dimensional falls risk. These findings should be taken into consideration when organizing falls rehabilitation programs.

However, although only Group M achieved a significantly reduced falls risk following rehabilitation (with no change noted in Group S) the number of reported falls both during the study and in the subsequent six months did not differ between groups. One reason for this may be the small sample size which did not allow for a detectable effect. Another reason may be an inaccurate or under reporting of falls on follow-up either due to the lack of asking participants to maintain a record of falls in a formal manner (i.e. falls diary), although no specific sampling frequency or type has been identified as being more reliable (Ganz et al. 2005)

5.5.2 Visual Measures

Interestingly, neither group demonstrated significant susceptibility to visual motion or space and motion discomfort symptoms at baseline, with both groups demonstrating similar scores to previously reported data for healthy younger adults (Guerraz et al. 2001; Pavlou et al. 2006; Pavlou et al. 2011), and differs to other studies indicating an increase in visual dependency with age (Lord and Webster 1990; Sundermier et al. 1996). Therefore significant changes would not be expected. However, there was a trend for the change in SCQ scores to differ between-groups at week 8, with Group S surprisingly reporting a worsening of space and motion discomfort (Group M: 2/7 worsening scores, Group S: 6/8) ; surpassing the cut-off for clinically significant symptoms. Although these findings were not corroborated with an increase in SVV tilt which remained unchanged in Group S, there was a trend for Group M to show a reduction (i.e. improvement) in SVV tilt

indicating reduced visual dependency. The current protocol for assessing SVV tilt may need modifying for an older population, the current test requires the participant use a computer mouse to control the test. Many of the participants were not conversant with using computers and were exposed to the visual stimulus for longer due to difficulties using the computer mouse. This may have affected results, although scores were not significantly different between groups and were not elevated compared to normative data collected at King's College London. For future studies this protocol should be modified and piloted to ensure appropriate use of equipment.

Interference with visual pathways either through disease or an increased visual reliance for balance function would be expected to increase falls risk in older people (Coleman et al. 2004; Sparto et al. 2006), with an increased susceptibility to visual motion stimuli being associated with increased postural instability (Sundermier et al. 1996; Borger et al. 1999; Loughlin and Redfern 2001) and poorer head stability (Sparto et al. 2006) in older people. Furthermore, individuals experiencing space and motion discomfort report symptoms of dizziness, disorientation and/or unsteadiness in situations involving visual-vestibular conflict (e.g. walking down supermarket aisles, crowds) or intense visual motion (e.g. watching wide-screen movies) (Bronstein 1995). The change i.e. worsening of SMD symptoms in Group S with 6/8 individuals reporting worsening SMD symptoms is therefore an unwelcome finding requiring further exploration

5.5.3 Subjective measures

At baseline, both groups report significant levels of vestibular symptoms included feelings of unsteadiness, giddiness and of being unable to stand or walk without support (Pavlou et al. 2006) (VSS-V). These symptoms are typical descriptors of vestibular dysfunction but may also be due to multiple other pathologies such as anxiety, orthostatic hypotension, weakness and musculo-skeletal problems. VSS-V baseline scores were similar to those previously reported (Liston et al. 2011) in older adult fallers experiencing multiple unexplained falls, but are lower than those reported in clinical studies of younger patients with vestibular dysfunction (Pavlou et al. 2006). For both groups, reductions in vestibular symptoms at final assessment were associated with improved ability to perform complex gait tasks (FGA). However, only Group M scores significantly improved to within normal ranges for the VSS-V at final assessment (Pavlou et al. 2006). These findings are not unexpected. A high general prevalence of vestibular dysfunction was suspected due to previous research reporting increased vestibular dysfunction in older adults and fallers (Jacobson et al. 2008; Agrawal et al. 2009; Liston et al. 2011). Therefore providing Group M with an intervention protocol that has proven efficacy in improving balance, gait and vestibular symptoms in individuals with known vestibular dysfunction (Yardley et al. 1992; Shepard and Telian 1995; Whitney et al. 2002; Cohen and Kimball 2003; Cohen and Kimball 2004; Pavlou et al. 2004; Yardley et al. 2004) would improve the same measures in a population with high prevalence of undiagnosed vestibular dysfunction.

That individuals in Group S significantly improved their balance confidence is of interest. Although baseline ABC scores were not significantly different, Group S scores were approximately 20 points lower than Group M (43.1 Vs. 65.3). As Group S' scores were lower, this may have provided scope for significant ABC improvement in this group. Group M did not significantly increase their ABC scores, although importantly their final ABC scores were within normal limits. Furthermore, Group M participants were provided with challenging balance tasks during the HEP, thus exposing their own postural instability. As Group S were not given complex postural tasks to perform and were reassured by therapists whilst performing simpler Otago exercises, this may have provided the mechanism for greater improvement in balance confidence in this group.

5.5.4 Implications for practice

Current guidelines dictate that strengthening, balance and gait training are recommended for the rehabilitation of older adult fallers (American Geriatrics Society and British Geriatrics Society 2010), however, no dosage, programs or intervention techniques are specified. A recent meta-analysis identified that high dosages of exercises (>50 hours) and challenging balance exercises had superior effects on falls rate (Sherrington et al. 2011). This pilot study provides evidence that moderate dosage exercise (c. 32 hours), if targeted, can have significant and large effects on falls risk and perceived symptoms of balance impairment; reducing risk and symptoms in older adult fallers to that of a normal healthy older adult. However, the long term effects on falls risk and rate are unknown at present and require investigation.

The Otago program has demonstrated greater effectiveness for reducing falls in older and frailer individuals rather than for younger older adults (Campbell et al. 1999). This study demonstrates that supplementing the Otago with multi-sensory exercises can provide significantly greater improvements in complex gait and falls risk in younger older adults. Further larger clinical trials are required to investigate the beneficial effect this may have on older adult fallers of varying ages in terms of gait ability and prospectively collected falls rate.

5.6 Conclusions

This was a pilot study to determine if providing a customised multisensory rehabilitation program to older adult fallers would provide any additional improvement in functional gait, subjective symptoms and physiological measures to a commonly used falls rehabilitation program. Although the sample size is small significant between-group differences with a significantly large effect size ($r \geq 0.5$) were noted for functional gait assessment and physiological falls risk with greater improvement for Group M. These results are very promising and warrant further investigation in trials with a larger cohort. Future studies should also investigate the long-term effect of treatment on falls risk and rate in a more robust manner.

Chapter 6. Discussion

The results of each experimental study have been discussed in the appropriate chapters. This discussion chapter will provide a summary of all results and a general overview of the project as a whole.

6.1 Context of project

Populations within the developed world are ageing, with older adults currently accounting for 16% of the total UK population; a proportion which is due to rise to 23% and 25% by 2035 and 2050 respectively (Office for National Statistics 2012). It has been well documented that with advancing years there is a decremental decrease in physiological, cognitive and integrative functions which may have a deleterious effect on postural stability, resulting in falls. The functional maintenance of balance requires not only appropriate strength but also, attention, cognitive function, movement strategies and the ability to reweight and integrate multiple sensory inputs from the visual, somatosensory and vestibular systems. Impaired performance in any of these functions may lead to postural instability and falls.

Falls are commonplace in older adults with approximately one-third falling at least once per annum (Scuffham et al. 2003), half of which experience multiple falls (Rubenstein 2006). Falls have wide-ranging effects both for the individual and the health services responsible for assessing and treating those at risk of or with a falls history. At an individual level, falls have both

psychological and physical effects. Fall events can lead to reductions in balance confidence and self efficacy, with increased anxiety which in turn may lead to reductions in activity levels, social isolation and reduced quality of life. Physically falls can lead to an array of injuries including lacerations, bruising and fractures, with mortality all too commonly associated with falls in older adults. Indeed in 2009 approximately 3000 deaths in older adults were due to accidental falls (accounting for 82% of all fall related deaths) (Source: Data.gov.uk). Injurious falls carry an associated cost for provider services, with hip fractures alone costing the NHS £2 billion to treat (Healthcare Quality Improvement Partnership 2011).

6.2 The assessment of older adult fallers

6.2.1 Physical measures

Chapter 2 focuses on performance of the Short Form Physiological Profile Assessment (PPA) in older adult fallers referred to a tertiary falls clinic. The PPA computes falls risk from the weighted Z scores of component PPA measures derived from age matched normative data (Lord et al. 1991; Lord et al. 1994; Lord et al. 1994). A default score (2x SD) was provided to older adults who could not complete the sway test (43% of all participants). However, 15% completed this test with a score greater than the 2 x SD default score. This misclassifies 58% (n=517) of all people tested and provides strong evidence to question the current validity of the composite PPA falls risk score derived from this calculation (Liston et al. 2012). However, the component tests are proven predictors of falls in older adults (Lord et al. 1991; Lord et al. 1994; Lord et al. 1994) and the calculation error

occurs when a moderate to high falls risk is already evident. Therefore the magnitude of the falls risk rather than the risk itself is questionable. A modification of the default score may rectify this problem and improve the sensitivity of the sway measure for tracking progress through rehabilitation. Raw data and variability across measures may still provide useful information regarding improvement or changes in measures that are significantly associated with falls.

This study also displayed significant differences in intra-individual variability between older and younger fallers. This may have implications for the provision of rehabilitation, in that younger groups which displayed impairments within fewer measures (i.e. strength, postural sway) may require a more focal management programme. However older adults with consistent deterioration across all measures and increased frailty may benefit from a more generic exercise programme such as the Otago (Campbell et al. 1997; Campbell et al. 1999; Robertson et al. 2002) which has been shown to be most beneficial for frailer older women over the age of 80 (Robertson et al. 2002).

The short form PPA, although validated for predicting falls risk in older adults (Lord et al. 2003) lacks a dynamic balance component, does not assess sensory integration nor does it contain any measure of vestibular function. As all are crucial for postural stability (and therefore preventing falls), these factors were assessed in combination with the PPA in Chapter 4. Age matched multiple fallers that were referred to a gerontology led falls clinic

were compared with older adults referred to a specialist neuro-otology clinic for vestibular testing (PV) and healthy individuals across a range of measures to assess sensory integration, gait, independence in activities of daily living and balance confidence.

Unsurprisingly healthy individuals performed significantly better than fallers across all physical measures and reported less falls, which is in agreement with current literature (Lord et al. 1991; Lord et al. 1994; Lord et al. 1994; Whitney et al. 2006; Wrisley and Kumar 2010). Healthy adults had normal performance on the FGA (Wrisley and Kumar 2010) and scores approaching normal for the PPA (Lord et al. 2003) and sensory organisation test. Interestingly fallers did not significantly differ to PV patients in PPA falls risk or computerised dynamic posturography scores, but fallers were older, reported more falls and had lower FGA scores; and therefore more impaired gait.

Due to the questionable validity of the PPA, its lack of a dynamic balance component and the higher prevalence of vestibular dysfunction in fallers (as discussed in Section 4) the study group have been advising the falls service within Guy's and St Thomas' NHS Foundation Trust regarding the implementation of the FGA into clinical practice as a screening tool for falls risk and vestibular dysfunction.

6.2.2 Subjective symptoms in older adults

Older adult fallers report significantly lower balance confidence, greater impairment in ADL's, greater anxiety and significantly greater levels of vestibular symptoms than healthy age matched older adults. All of which can be improved in cohorts of patients with balance disorders following appropriate rehabilitation (Whitney et al. 2002; Cohen and Kimball 2003; Pavlou et al. 2004). Interestingly fallers only differed from PV patients in scores of functional ADL performance, with fallers reporting greater impairment. Although fallers and PV patients did not differ on overall reported vestibular symptoms there was a difference in the types of symptoms reported. Fallers reported significantly more sensations of "feeling unsteady, about to lose balance" than PV patients. Dizziness is commonly perceived as a sign of vestibular dysfunction; however unsteadiness was the biggest complaint for fallers.

Dizziness is a common complaint in older adults (Agrawal et al. 2009), is considered as a geriatric syndrome (Tinetti et al. 2000), has multiple causes (e.g. cardiovascular problem or drug interactions (Lawson and Bamliou 2005; Lawson et al. 2008)) and is a common symptom reported by individuals with vestibular dysfunction. However, in this study 17 fallers did not report any dizziness, 14 of which were found to have clinically significant vestibular dysfunction (in contrast 6 fallers with vestibular dysfunction reported rotatory dizziness). This atypical vestibular presentation in fallers highlights the difficulties for the clinician when assessing fallers to identify vestibular dysfunction. The clinician should be suspicious of vestibular dysfunction

whenever feelings of unsteadiness or light headedness are reported rather than specific symptoms of rotatory dizziness on head movement.

6.2.3 Dual tasking ability / multi tasking in healthy older adults

A number of studies exist to describe the reduction in dual task ability in older adults (Lajoie et al. 1996; Maylor and Wing 1996; Maki et al. 2001; Alexander et al. 2005; Sturnieks et al. 2008). Problems in dual tasking may become evident when stopping walking when talking (Lundin-Olsson et al. 1997) or when performing more complex tasks when standing, stepping or crossing an obstacle (Silsupadol et al. 2006; Sturnieks et al. 2008). However, dual tasking is the norm for day-to-day life and current dual task protocols do not attempt to replicate the complexity of everyday situations, where otherwise fit and healthy older adults experience falls.

A bi-modal multi-task test was designed to assess the interaction between a postural visual spatial task and a non-postural auditory spatial task in healthy, non-falling younger and older adults. Younger adults performed better than older adults and prioritised the stepping task in accordance with the posture first strategy; results which were not unexpected and in line with current literature. Unexpectedly, older adults did not consistently prioritise the postural task as would be expected within the posture first strategy. The temporally regular auditory task was prioritised instead of the postural task, leading to significantly increased dual task costs for response time and accuracy for the latter.

This is the first time a bi-modal spatial multi-tasking test has been utilised to create a complex task. The elevated complexity in the protocol, coupled with bi-modal spatial tasking may create sufficient competition for resources, or test attention switching capabilities to an extent where attentional prioritisations have to be made by older adults. This study may provide a framework to investigate alterations in posture first in healthy older adults and fallers, however, a range of larger studies need to be undertaken to determine why these changes occur and whether they are associated with elevated falls risk.

Studies are currently underway to determine the effect of bi-modal spatial multi-tasking in PV patients with the Department of Neuro-Otology, National Hospital for Neurology and Neurosurgery. Further studies are currently being planned to investigate the effectiveness of the multi-task protocol in selecting cases for study (i.e. to identify posture first vs. posture second), to assess the validity of the protocol in assessing falls risk in older adults, to investigate the effect of timing of stimulus presentation and modification of peripheral inputs on response time and accuracy. Further work will include determining whether this type of protocol would be beneficial as a variable priority multi-task training tool to improve dual task ability in older adults.

6.2.4 Clinical measures of vestibular function

At present the assessment of vestibular function is not specifically recommended in current guidelines for older adult fallers (American Geriatrics Society and British Geriatrics Society 2010). Chapter 4 identifies

that a large proportion of fallers (80%) have an unrecognised vestibular disorder that may be a significant contributor to their feelings of instability and reported falls. This proportion is significantly higher than in a healthy older adult population drawn from the same geographic area. The high proportion of impaired vestibular function in fallers (80%) is similar to reported data (Jacobson et al. 2008; Agrawal et al. 2009), however, Agrawal et al did not use clinical vestibular function testing. Therefore, the prevalence of clinically significant vestibular dysfunction rather than impaired sensory integration is not known. Jacobson et al (Jacobson et al. 2008) failed to differentiate fallers from non-fallers and therefore determining if vestibular dysfunction was more prevalent in fallers cannot be discerned from this study. The data presented in Chapter 4 begins to bridge this gap. By comparing ambulatory community dwelling fallers with age-matched healthy older adults, the prevalence of vestibular dysfunction in fallers and non-fallers alike could be observed.

This study highlights the need for further larger studies to determine the prevalence of vestibular dysfunction in older adults experiencing unexplained falls, and to provide suitable predictors for vestibular dysfunction in older adult fallers. Vestibular testing of all fallers would not be a suitable or cost effective solution for clinical practice due to the lack of appropriate clinical centres for testing, expense of testing and provocative nature of tests. However, education regarding the high prevalence of vestibular dysfunction in older adult fallers and simple bed side tests to screen for peripheral and central vestibular dysfunction may provide a significant improvement to the

assessment of older adult fallers. Possible tests to be explored could be the head thrust test, VOR suppression and the dynamic visual acuity test. This work has led to the development of a new vestibular pathway for the Southwark and Lambeth Integrated care Pathway for Falls (SLIPS) (see appendix 12) which is currently under consultation.

6.3 The rehabilitation of fallers

Chapter 5 assesses a novel falls rehabilitation programme aimed at improving utilisation of vestibular cues, sensory integration and dynamic balance (including gait). This chapter investigated the effect of supplementing the well-known OTAGO programme with either a stretching programme (control) or a customised multisensory rehabilitation. The Multisensory rehabilitation contained exercises commonly used in vestibular rehabilitation, to promote central adaptation, sensory reweighting and sensory integration. Vestibular rehabilitation has proven efficacy in improving balance function and reducing subjective symptoms in peripheral and central balance disorders and is equally effective regardless of age (Whitney et al. 2002; Cohen and Kimball 2003; Cohen and Kimball 2004). Recently, multisensory rehabilitation has begun to be implemented in older adults without known vestibular dysfunction (Beling and Roller 2009; Yang et al. 2012) to investigate improvements in balance function. Promising effects in community dwelling older adults have been reported, but no study to date has assessed the effectiveness of these programmes in fallers.

6.3.1 Changes in physical measures of falls risk

Individuals receiving additional stretching exercises did not show significant improvements on any physical measure, demonstrating a lack of effect for the Otago programme on complex gait and PPA falls risk. Multi-sensory rehabilitation on the other hand, produced significant reductions in PPA falls risk and improvements in FGA scores with large effect sizes ($r=0.63$) over the course of the 8-week programme. Changes in FGA scores achieved a minimal clinically significant change considered to be 6 points (Alsalaheen et al. 2010). At final assessment, both FGA and PPA scores showed that patients completing the multi-sensory intervention were no longer at risk for falls according to published cut-offs for the measures (Lord et al. 2003; Wrisley and Kumar 2010) and were similar to those for healthy older adults. Interestingly, these changes occurred after only 32 hours of intervention, significantly less than the 50 hours recommended in a recent meta-analysis (Sherrington et al. 2011). As the HEP was delivered at home, further reductions in intervention time could occur by combining the multi-sensory exercises into the falls class, reducing programme time to approximately 24 hours. If proven to be effective in larger trials, this could have significant implications on rehabilitation costs. A funding application is currently underway in conjunction with Guy's and St Thomas' NHS Foundation Trust to perform a 12-month pilot study to determine the effectiveness of a multi-sensory rehabilitation programme.

This study has a number of limitations; firstly it was not possible to identify patient groups that may benefit most from this intervention due the small

sample size. Secondly, this study did not detect a change in falls rate although falls risk was significantly reduced. This may have been due to insufficient numbers to enable an effect to be detected but may also have been due to using telephone follow-up to collect falls information at 6 months post-rehabilitation. However, these issues are being addressed in the study currently being designed with Guy's and St Thomas'.

6.3.2 Changes in subjective symptoms

At baseline both groups reported similar levels of vestibular symptoms such as giddiness, unsteadiness and feeling unable to stand without support, with scores borderline for vestibular dysfunction (Pavlou et al. 2006). Only the multi-sensory rehabilitation group significantly reduced vestibular symptoms, with final scores within normal ranges. Whereas the stretching group continued to report symptom levels consistent with vestibular dysfunction, indicating a lack of effect of the Otago in targeting these types of symptoms. However, although still reporting vestibular symptoms, balance confidence was significantly improved in the stretching group but not in the multi-sensory rehabilitation group. This may be reflected by the less challenging nature of the seated stretching programme as opposed to the complex, challenging and on occasion disorienting exercises given to the multisensory group. Although there was no significant difference between ABC scores (within or between group) at any time point, the multi-sensory rehabilitation group had higher i.e. better ABC scores through-out the study duration, with final scores within normal levels (Lajoie and Gallagher 2004). Whereas those in the stretching group continued to indicate an increased falls risk. Greater

improvements in the stretching group may have occurred due to their lower (although not significantly) ABC baseline scores. These lower scores could have provided a greater capacity for change in the stretching group, as the multi-sensory group were nearer to normal scores at baseline.

An interesting, yet non-significant finding is the apparent increase in space and motion discomfort (SMD) reported by individuals undertaking the stretching programme (i.e. control group). At Week-8 the stretching group reported abnormal levels of SMD (Pavlou et al. 2006) which could indicate an increase in visual dependency, although SVV scores, a perceptual level measure of visual dependency (Guerraz et al. 2001) did not increase. These increases may have occurred due to patients' using optic fixation techniques when trying to maintain balance with eyes open. This trend was not observed in the multi-sensory rehabilitation group who were exposed to complex visual environments (i.e. chequerboard patterns and stripes) when practising balance exercises. The change in SMD needs to be further investigated as this study did not have sufficient sample size to detect significant changes.

6.3.3 Clinical Implications and planned service changes

This project has led to a number of planned changes within tertiary services within one of London's largest NHS trusts. Firstly Chapter 2 questions the validity of the PPA in its current use as an outcome measure to measure change in falls risk. Since the publication of the results of this study discussions are currently underway with the SLIPS pathway managers to determine other possible outcome measures to be used. Following

dissemination of the results from Chapter 4, a vestibular pathway within the SLIPS pathway for fallers to identify and treat those with vestibular disorders has been developed. Discussions are currently underway with consultant geriatricians (A. Hopper and F. Martin) to assist with piloting this. Alongside the changes to assessment of fallers, the researchers are currently applying for funding to perform an assessment of the effects of the Otago (including SMD symptoms). This will be compared with a new multi-sensory rehabilitation programme based upon the protocol developed in this thesis (Chapter 5). If proven to be effective in larger clinical trials, this thesis and follow on studies could provide a new framework for the assessment and rehabilitation of older adults at risk for falls.

References

- Agrawal, Y., J. P. Carey, et al. (2009). "Disorders of balance and vestibular function in US adults: data from the National Health and Nutrition Examination Survey, 2001-2004." Arch Intern Med **169**(10): 938-44.
- Alexander, N. B., J. A. Ashton-Miller, et al. (2005). "Age differences in timed accurate stepping with increasing cognitive and visual demand: a walking trail making test." J Gerontol A Biol Sci Med Sci **60**(12): 1558-62.
- Alsalaheen, B. A., A. Mucha, et al. (2010). "Vestibular rehabilitation for dizziness and balance disorders after concussion." J Neurol Phys Ther **34**(2): 87-93.
- American Geriatrics Society and British Geriatrics Society (2010). "Summary of the Updated American Geriatrics Society/British Geriatrics Society Clinical Practice Guideline for Prevention of Falls in Older Persons." Journal of the American Geriatrics Society.
- American Geriatrics Society, British Geriatrics Society, et al. (2001). "Guideline for the Prevention of Falls in Older Persons." Journal of the American Geriatrics Society **49**: 664-672.
- Badke, M. B., T. A. Shea, et al. (2004). "Outcomes after rehabilitation for adults with balance dysfunction." Arch Phys Med Rehabil **85**(2): 227-33.
- Baloh, R. W., J. Enrietto, et al. (2001). "Age-related changes in vestibular function: a longitudinal study." Ann N Y Acad Sci **942**: 210-9.
- Baloh, R. W., S. H. Ying, et al. (2003). "A longitudinal study of gait and balance dysfunction in normal older people." Arch Neurol **60**(6): 835-9.
- Barnett, A., B. Smith, et al. (2003). "Community-based group exercise improves balance and reduces falls in at-risk older people: a randomised controlled trial." Age Ageing **32**(4): 407-14.
- Barra, J., A. Bray, et al. (2006). "Increasing cognitive load with increasing balance challenge: recipe for catastrophe." Exp Brain Res **174**(4): 734-45.
- Bath, P. A. and K. Morgan (1999). "Differential risk factor profiles for indoor and outdoor falls in older people living at home in Nottingham, UK." Eur J Epidemiol **15**(1): 65-73.
- Bauby, C. E. and A. D. Kuo (2000). "Active control of lateral balance in human walking." J Biomech **33**(11): 1433-40.
- Beling, J. and M. Roller (2009). "Multifactorial intervention with balance training as a core component among fall-prone older adults." J Geriatr Phys Ther **32**(3): 125-33.
- Bell, F. (1998). Principles of Mechanics and Biomechanics. Cheltenham, Stanley Thornes.
- Berg, K. O., S. L. Wood-Dauphinee, et al. (1992). "Measuring balance in the elderly: validation of an instrument." Can J Public Health **83 Suppl 2**: S7-11.
- Berg, W. P. and L. A. Murdock (2011). "Age-related differences in locomotor targeting performance under structural interference." Age Ageing **40**(3): 324-9.
- Blake, A. J., K. Morgan, et al. (1988). "Falls by elderly people at home: prevalence and associated factors." Age Ageing **17**(6): 365-72.
- Ble, A., S. Volpato, et al. (2005). "Executive function correlates with walking speed in older persons: the InCHIANTI study." J Am Geriatr Soc **53**(3): 410-5.
- Bloem, B. R., Y. A. Grimbergen, et al. (2006). "The 'posture second' strategy: a review of wrong priorities in Parkinson's disease." J Neurol Sci **248**(1-2): 196-204.
- Bohannon, R. W. (1997). "Comfortable and maximum walking speed of adults aged 20-79 years: reference values and determinants." Age Ageing **26**(1): 15-9.

- Bohl, A. A., P. A. Fishman, et al. (2010). "A Longitudinal Analysis of Total 3-Year Healthcare Costs for Older Adults Who Experience a Fall Requiring Medical Care." J Am Geriatr Soc.
- Borger, L. L., S. L. Whitney, et al. (1999). "The influence of dynamic visual environments on postural sway in the elderly." J Vestib Res **9**(3): 197-205.
- Brauer, S. G., M. Woollacott, et al. (2002). "The influence of a concurrent cognitive task on the compensatory stepping response to a perturbation in balance-impaired and healthy elders." Gait Posture **15**(1): 83-93.
- British Geriatrics Society and American Geriatrics Society (2011). "Summary of the Updated American Geriatrics Society / British Geriatrics Society Clinical Practice Guideline for Prevention of Falls in Older Adults." Journal of the American Geriatrics Society **59**(1): 148-157.
- Bronstein, A. M. (1995). "The visual vertigo syndrome." Acta Otolaryngol Suppl **520 Pt 1**: 45-8.
- Bronstein, A. M. (1995). "Visual vertigo syndrome: clinical and posturography findings." J Neurol Neurosurg Psychiatry **59**(5): 472-6.
- Bruce, D. G., A. Devine, et al. (2002). "Recreational physical activity levels in healthy older women: the importance of fear of falling." J Am Geriatr Soc **50**(1): 84-9.
- Buatois, S., R. Gueguen, et al. (2006). "Posturography and risk of recurrent falls in healthy non-institutionalized persons aged over 65." Gerontology **52**(6): 345-52.
- Buchanan, J. J. and F. B. Horak (2001). "Vestibular loss disrupts control of head and trunk on a sinusoidally moving platform." J Vestib Res **11**(6): 371-89.
- Callisaya, M. L., L. Blizzard, et al. (2009). "A population-based study of sensorimotor factors affecting gait in older people." Age Ageing **38**(3): 290-5.
- Campbell, A. J., M. J. Borrie, et al. (1989). "Risk factors for falls in a community-based prospective study of people 70 years and older." J Gerontol **44**(4): M112-7.
- Campbell, A. J., M. J. Borrie, et al. (1990). "Circumstances and consequences of falls experienced by a community population 70 years and over during a prospective study." Age Ageing **19**(2): 136-41.
- Campbell, A. J., M. C. Robertson, et al. (1999). "Falls prevention over 2 years: a randomized controlled trial in women 80 years and older." Age Ageing **28**(6): 513-8.
- Campbell, A. J., M. C. Robertson, et al. (1997). "Randomised controlled trial of a general practice programme of home based exercise to prevent falls in elderly women." BMJ **315**(7115): 1065-9.
- Carpenter, M. G., A. L. Adkin, et al. (2006). "Postural, physiological and psychological reactions to challenging balance: does age make a difference?" Age Ageing **35**(3): 298-303.
- Centers for Disease Control and Prevention (1996). "Incidence and costs to Medicare of fractures among Medicare beneficiaries aged > or = 65 years--United States, July 1991-June 1992." MMWR Morb Mortal Wkly Rep **45**(41): 877-83.
- Centers for Disease Control and Prevention and The Merck Company Foundation (2007). *The State of Aging and Health in America 2007*.
- Clark, R. D., S. R. Lord, et al. (1993). "Clinical parameters associated with falls in an elderly population." Gerontology **39**(2): 117-23.
- Close, J., M. Ellis, et al. (1999). "Prevention of falls in the elderly trial (PROFET): a randomised controlled trial." Lancet **353**(9147): 93-7.
- Cohen, H. S. and K. T. Kimball (2000). "Development of the vestibular disorders activities of daily living scale." Arch Otolaryngol Head Neck Surg **126**(7): 881-7.

- Cohen, H. S. and K. T. Kimball (2003). "Increased independence and decreased vertigo after vestibular rehabilitation." Otolaryngol Head Neck Surg **128**(1): 60-70.
- Cohen, H. S. and K. T. Kimball (2004). "Decreased ataxia and improved balance after vestibular rehabilitation." Otolaryngol Head Neck Surg **130**(4): 418-25.
- Coleman, A. L., K. Stone, et al. (2004). "Higher risk of multiple falls among elderly women who lose visual acuity." Ophthalmology **111**(5): 857-62.
- Colledge, N. R., J. A. Wilson, et al. (1994). "The prevalence and characteristics of dizziness in an elderly community." Age Ageing **23**(2): 117-20.
- Coppin, A. K., A. Shumway-Cook, et al. (2006). "Association of executive function and performance of dual-task physical tests among older adults: analyses from the InChianti study." Age Ageing **35**(6): 619-24.
- Cumming, R. G., G. Salkeld, et al. (2000). "Prospective study of the impact of fear of falling on activities of daily living, SF-36 scores, and nursing home admission." J Gerontol A Biol Sci Med Sci **55**(5): M299-305.
- Curthoys, I. S. and G. M. Halmagyi (1995). "Vestibular compensation: a review of the oculomotor, neural, and clinical consequences of unilateral vestibular loss." J Vestib Res **5**(2): 67-107.
- Davis, J. R., A. D. Campbell, et al. (2009). "The relationship between fear of falling and human postural control." Gait Posture **29**(2): 275-9.
- Day, L., B. Fildes, et al. (2002). "Randomised factorial trial of falls prevention among older people living in their own homes." BMJ **325**(7356): 128.
- Deandrea, S., E. Lucenteforte, et al. (2010). "Risk factors for falls in community-dwelling older people: a systematic review and meta-analysis." Epidemiology **21**(5): 658-68.
- Department of Health (2001). National Service Framework For Older People.
- Der, G. and I. J. Deary (2006). "Age and sex differences in reaction time in adulthood: results from the United Kingdom Health and Lifestyle Survey." Psychol Aging **21**(1): 62-73.
- Dommes, A. and V. Cavallo (2011). "The role of perceptual, cognitive, and motor abilities in street-crossing decisions of young and older pedestrians." Ophthalmic Physiol Opt **31**(3): 292-301.
- Donald, I. P. and C. J. Bulpitt (1999). "The prognosis of falls in elderly people living at home." Age Ageing **28**(2): 121-5.
- Dunn, J. E., M. A. Rudberg, et al. (1992). "Mortality, disability, and falls in older persons: the role of underlying disease and disability." Am J Public Health **82**(3): 395-400.
- Elley, C. R., M. C. Robertson, et al. (2008). "Effectiveness of a falls-and-fracture nurse coordinator to reduce falls: a randomized, controlled trial of at-risk older adults." J Am Geriatr Soc **56**(8): 1383-9.
- Fiatarone, M. A., E. F. O'Neill, et al. (1994). "Exercise training and nutritional supplementation for physical frailty in very elderly people." N Engl J Med **330**(25): 1769-75.
- Field, A. P. (2005). Discovering statistics using SPSS : (and sex, drugs and rock 'n' roll). London, Sage Publications.
- Fleming, J., F. E. Matthews, et al. (2008). "Falls in advanced old age: recalled falls and prospective follow-up of over-90-year-olds in the Cambridge City over-75s Cohort study." BMC Geriatr **8**: 6.
- Frick, K. D., J. Y. Kung, et al. (2010). "Evaluating the cost-effectiveness of fall prevention programs that reduce fall-related hip fractures in older adults." J Am Geriatr Soc **58**(1): 136-41.
- Gananca, F. F., J. M. Gazzola, et al. (2010). "Elderly falls associated with benign paroxysmal positional vertigo." Braz J Otorhinolaryngol **76**(1): 113-20.

- Ganz, D. A., T. Higashi, et al. (2005). "Monitoring falls in cohort studies of community-dwelling older people: effect of the recall interval." J Am Geriatr Soc **53**(12): 2190-4.
- Gates, S., J. D. Fisher, et al. (2008). "Multifactorial assessment and targeted intervention for preventing falls and injuries among older people in community and emergency care settings: systematic review and meta-analysis." BMJ **336**(7636): 130-3.
- Gauchard, G. C., P. Gangloff, et al. (2003). "Physical activity improves gaze and posture control in the elderly." Neurosci Res **45**(4): 409-17.
- Gauchard, G. C., G. Vancon, et al. (2004). "Physical activity after retirement enhances vestibulo-ocular reflex in elderly humans." Neurosci Lett **360**(1-2): 17-20.
- Gerdhem, P., K. A. Ringsberg, et al. (2005). "Clinical history and biologic age predicted falls better than objective functional tests." J Clin Epidemiol **58**(3): 226-32.
- Gleason, C. E., R. E. Gangnon, et al. (2009). "Increased risk for falling associated with subtle cognitive impairment: secondary analysis of a randomized clinical trial." Dement Geriatr Cogn Disord **27**(6): 557-63.
- Gottlob, I. (2000). "Ups and downs of optokinetic nystagmus." Br J Ophthalmol **84**(5): 445-6.
- Graafmans, W. C., M. E. Ooms, et al. (1996). "Different risk profiles for hip fractures and distal forearm fractures: a prospective study." Osteoporos Int **6**(6): 427-31.
- Graafmans, W. C., M. E. Ooms, et al. (1996). "Falls in the elderly: a prospective study of risk factors and risk profiles." Am J Epidemiol **143**(11): 1129-36.
- Green, D. A., J. L. Zhu, et al. (2010). "Slalom walking with prism disorientation: impact on verbal and spatial tasks." Aviat Space Environ Med **81**(8): 728-34.
- Gribbin, J., R. Hubbard, et al. (2009). "Incidence and mortality of falls amongst older people in primary care in the United Kingdom." QJM **102**(7): 477-83.
- Guerraz, M., L. Yardley, et al. (2001). "Visual vertigo: symptom assessment, spatial orientation and postural control." Brain **124**(Pt 8): 1646-56.
- Gunter, K. B., K. N. White, et al. (2000). "Functional mobility discriminates nonfallers from one-time and frequent fallers." J Gerontol A Biol Sci Med Sci **55**(11): M672-6.
- Guyatt, G., S. Walter, et al. (1987). "Measuring change over time: assessing the usefulness of evaluative instruments." J Chronic Dis **40**(2): 171-8.
- Hain, T. C. and J. O. Helminski (2007). Anatomy and physiology of the normal vestibular system. Vestibular Rehabilitation. S. J. Herdman. Philadelphia, F.A. Davis Company: 2-18.
- Hall, C. D., K. V. Echt, et al. (2011). "Cognitive and motor mechanisms underlying older adults' ability to divide attention while walking." Phys Ther **91**(7): 1039-50.
- Hall, C. D., L. Heusel-Gillig, et al. (2010). "Efficacy of gaze stability exercises in older adults with dizziness." J Neurol Phys Ther **34**(2): 64-9.
- Hall, C. D., M. C. Schubert, et al. (2004). "Prediction of fall risk reduction as measured by dynamic gait index in individuals with unilateral vestibular hypofunction." Otol Neurotol **25**(5): 746-51.
- Hausdorff, J. M., D. A. Rios, et al. (2001). "Gait variability and fall risk in community-living older adults: a 1-year prospective study." Arch Phys Med Rehabil **82**(8): 1050-6.
- Hawkes, T. D., K. C. Siu, et al. (2011). "Why does older adults' balance become less stable when walking and performing a secondary task? Examination of attentional switching abilities." Gait Posture.

- Healthcare Quality Improvement Partnership (2008). Patient and Public Involvement: Older People's Experiences of Falls and Bone Health Services (England)
- Healthcare Quality Improvement Partnership (2011). "The National Hip Fracture Database National Report 2011."
- Hendriks, M. R., M. H. Bleijlevens, et al. (2008). "Lack of effectiveness of a multidisciplinary fall-prevention program in elderly people at risk: a randomized, controlled trial." J Am Geriatr Soc **56**(8): 1390-7.
- Herdman, S. J. (1997). "Advances in the treatment of vestibular disorders." Phys Ther **77**(6): 602-18.
- Herdman, S. J., P. Blatt, et al. (2000). "Falls in patients with vestibular deficits." Am J Otol **21**(6): 847-51.
- Herdman, S. J., M. C. Schubert, et al. (2003). "Recovery of dynamic visual acuity in unilateral vestibular hypofunction." Arch Otolaryngol Head Neck Surg **129**(8): 819-24.
- Herdman, S. J., R. J. Tusa, et al. (1998). "Computerized dynamic visual acuity test in the assessment of vestibular deficits." Am J Otol **19**(6): 790-6.
- Herman, T., N. Inbar-Borovsky, et al. (2008). "The Dynamic Gait Index in healthy older adults: The role of stair climbing, fear of falling and gender." Gait Posture.
- Hill, K., N. Kerse, et al. (2002). "Falls: a comparison of trends in community, hospital and mortality data in older Australians." Aging Clin Exp Res **14**(1): 18-27.
- Hillier, S. L. and V. Hollohan (2007). "Vestibular rehabilitation for unilateral peripheral vestibular dysfunction." Cochrane Database Syst Rev(4): CD005397.
- Hilton, M. and D. Pinder (2004). "The Epley (canalith repositioning) manoeuvre for benign paroxysmal positional vertigo." Cochrane Database Syst Rev(2): CD003162.
- Hirasaki, E., T. Kubo, et al. (1993). "Analysis of head and body movements of elderly people during locomotion." Acta Otolaryngol Suppl **501**: 25-30.
- Hirasaki, E., S. T. Moore, et al. (1999). "Effects of walking velocity on vertical head and body movements during locomotion." Exp Brain Res **127**(2): 117-30.
- Hoidrup, S., T. I. Sorensen, et al. (2003). "Incidence and characteristics of falls leading to hospital treatment: a one-year population surveillance study of the Danish population aged 45 years and over." Scand J Public Health **31**(1): 24-30.
- Honaker, J. A. and N. T. Shepard (2011). "Use of the Dynamic Visual Acuity Test as a screener for community-dwelling older adults who fall." J Vestib Res **21**(5): 267-76.
- Horak, F. B. (1987). "Clinical measurement of postural control in adults." Phys Ther **67**(12): 1881-5.
- Horak, F. B. (2006). "Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls?" Age Ageing **35** **Suppl 2**: ii7-ii11.
- Horak, F. B., R. Dickstein, et al. (2002). "Diabetic neuropathy and surface sway-referencing disrupt somatosensory information for postural stability in stance." Somatosens Mot Res **19**(4): 316-26.
- Horak, F. B. and L. M. Nashner (1986). "Central programming of postural movements: adaptation to altered support-surface configurations." J Neurophysiol **55**(6): 1369-81.
- Hu, M. H. and M. H. Woollacott (1994). "Multisensory training of standing balance in older adults: I. Postural stability and one-leg stance balance." J Gerontol **49**(2): M52-61.

- Hu, M. H. and M. H. Woollacott (1994). "Multisensory training of standing balance in older adults: II. Kinematic and electromyographic postural responses." J Gerontol **49**(2): M62-71.
- Huxhold, O., S. C. Li, et al. (2006). "Dual-tasking postural control: aging and the effects of cognitive demand in conjunction with focus of attention." Brain Res Bull **69**(3): 294-305.
- Jacob, R. G., Lilienfeld, S.O., Furman, J.M.R., Durrant, J.D., Turner, S.M. (1989). "Panic disorder with vestibular dysfunction: further clinical observations and description of space and motion phobic stimuli. ." Journal of Anxiety Disorders. **3**: 117-130.
- Jacobson, G. P., D. L. McCaslin, et al. (2008). "Significant vestibular system impairment is common in a cohort of elderly patients referred for assessment of falls risk." J Am Acad Audiol **19**(10): 799-807.
- Jensen, J., L. Nyberg, et al. (2003). "Fall and injury prevention in residential care--effects in residents with higher and lower levels of cognition." J Am Geriatr Soc **51**(5): 627-35.
- Jonsson, R., E. Sixt, et al. (2004). "Prevalence of dizziness and vertigo in an urban elderly population." J Vestib Res **14**(1): 47-52.
- Jung, J. Y., J. S. Kim, et al. (2009). "Effect of vestibular rehabilitation on dizziness in the elderly." Am J Otolaryngol **30**(5): 295-9.
- Kelsey, J. L. and E. J. Samelson (2009). "Variation in risk factors for fractures at different sites." Curr Osteoporos Rep **7**(4): 127-33.
- Kennedy, T. and L. Coppard (1987). "The prevention of falls in later life. A report of the Kellogg International Work Group on the Prevention of Falls by the Elderly." Danish Medical Bulletin **34**(4): 1-24.
- Koceja, D. M., D. Allway, et al. (1999). "Age differences in postural sway during volitional head movement." Arch Phys Med Rehabil **80**(12): 1537-41.
- Koch, H. and M. Smith (1985). Office-based ambulatory care for patients 75 years old and over: National Ambulatory Medical Care Survey, 1980 and 1981. N. A. D. N. 110. Washington, DC, US Department of Health and Human Services, Public Health Service, National Center for Health Statistics.
- Kosnik, W., L. Winslow, et al. (1988). "Visual changes in daily life throughout adulthood." J Gerontol **43**(3): P63-70.
- Kristinsdottir, E. K., G. B. Jarnlo, et al. (2000). "Asymmetric vestibular function in the elderly might be a significant contributor to hip fractures." Scand J Rehabil Med **32**(2): 56-60.
- Kristinsdottir, E. K., E. Nordell, et al. (2001). "Observation of vestibular asymmetry in a majority of patients over 50 years with fall-related wrist fractures." Acta Otolaryngol **121**(4): 481-5.
- Kuo, A. D., R. A. Speers, et al. (1998). "Effect of altered sensory conditions on multivariate descriptors of human postural sway." Exp Brain Res **122**(2): 185-95.
- Lajoie, Y. and S. P. Gallagher (2004). "Predicting falls within the elderly community: comparison of postural sway, reaction time, the Berg balance scale and the Activities-specific Balance Confidence (ABC) scale for comparing fallers and non-fallers." Arch Gerontol Geriatr **38**(1): 11-26.
- Lajoie, Y., N. Teasdale, et al. (1996). Attentional demands for walking: Age-related changes. Advances in Psychology: Changes in Sensory Motor Behaviour in Aging. A. Ferrandez and N. Teasdale. Amsterdam, Elsevier Science BV. **114**: 235-256.
- Lawson, J. and D. E. Bamiou (2005). "Dizziness in the older person." Reviews in Clinical Gerontology **15**: 187-206.
- Lawson, J., D. E. Bamiou, et al. (2008). "Positional vertigo in a Falls Service." Age Ageing **37**(5): 585-9.

- Lawson, J., I. Johnson, et al. (2005). "Benign paroxysmal positional vertigo: clinical characteristics of dizzy patients referred to a Falls and Syncope Unit." QJM **98**(5): 357-64.
- Lehtola, S., P. Koistinen, et al. (2006). "Falls and injurious falls late in home-dwelling life." Arch Gerontol Geriatr **42**(2): 217-24.
- Lezak, M. D. (2005). Neuropsychological Assessment. New York, Oxford University Press Inc.
- Li, F., P. Harmer, et al. (2005). "Tai Chi and fall reductions in older adults: a randomized controlled trial." J Gerontol A Biol Sci Med Sci **60**(2): 187-94.
- Li, W., T. H. Keegan, et al. (2006). "Outdoor falls among middle-aged and older adults: a neglected public health problem." Am J Public Health **96**(7): 1192-200.
- Liston, M., D. E. Bamiou, et al. (2011). "Vestibular function in unexplained falls." Balance Focus(Winter 2011).
- Liston, M. B., M. Pavlou, et al. (2012). "The Physiological Profile Assessment: Clinical validity of the postural sway measure and comparison of impairments by age." European Geriatric Medicine **3**(1): 5-8.
- Liu-Ambrose, T., M. G. Donaldson, et al. (2008). "Otago home-based strength and balance retraining improves executive functioning in older fallers: a randomized controlled trial." J Am Geriatr Soc **56**(10): 1821-30.
- Liu-Ambrose, T., L. A. Katarynych, et al. (2009). "Dual-task gait performance among community-dwelling senior women: the role of balance confidence and executive functions." J Gerontol A Biol Sci Med Sci **64**(9): 975-82.
- Liu-Ambrose, T., K. M. Khan, et al. (2004). "Resistance and agility training reduce fall risk in women aged 75 to 85 with low bone mass: a 6-month randomized, controlled trial." J Am Geriatr Soc **52**(5): 657-65.
- Liu-Ambrose, T. Y., M. C. Ashe, et al. (2008). "Increased risk of falling in older community-dwelling women with mild cognitive impairment." Phys Ther **88**(12): 1482-91.
- Lorbach, E. R., K. E. Webster, et al. (2007). "Physiological falls risk assessment in older people with Alzheimer's disease." Dement Geriatr Cogn Disord **24**(4): 260-5.
- Lord, S. R. (1990). "Falls in the elderly: admissions, bed use, outcome and projections." Med J Aust **153**(2): 117-8.
- Lord, S. R. and R. D. Clark (1996). "Simple physiological and clinical tests for the accurate prediction of falling in older people." Gerontology **42**(4): 199-203.
- Lord, S. R., R. D. Clark, et al. (1991). "Physiological factors associated with falls in an elderly population." J Am Geriatr Soc **39**(12): 1194-200.
- Lord, S. R., R. D. Clark, et al. (1991). "Postural stability and associated physiological factors in a population of aged persons." J Gerontol **46**(3): M69-76.
- Lord, S. R. and R. C. Fitzpatrick (2001). "Choice stepping reaction time: a composite measure of falls risk in older people." J Gerontol A Biol Sci Med Sci **56**(10): M627-32.
- Lord, S. R., L. M. March, et al. (2003). "Differing risk factors for falls in nursing home and intermediate-care residents who can and cannot stand unaided." J Am Geriatr Soc **51**(11): 1645-50.
- Lord, S. R., D. McLean, et al. (1992). "Physiological factors associated with injurious falls in older people living in the community." Gerontology **38**(6): 338-46.
- Lord, S. R., H. B. Menz, et al. (2003). "A physiological profile approach to falls risk assessment and prevention." Phys Ther **83**(3): 237-52.
- Lord, S. R., S. M. Murray, et al. (2002). "Sit-to-stand performance depends on sensation, speed, balance, and psychological status in addition to strength in older people." J Gerontol A Biol Sci Med Sci **57**(8): M539-43.

- Lord, S. R., M. W. Rogers, et al. (1999). "Lateral stability, sensorimotor function and falls in older people." J Am Geriatr Soc **47**(9): 1077-81.
- Lord, S. R., P. N. Sambrook, et al. (1994). "Postural stability, falls and fractures in the elderly: results from the Dubbo Osteoporosis Epidemiology Study." Med J Aust **160**(11): 684-5, 688-91.
- Lord, S. R., A. Tiedemann, et al. (2005). "The effect of an individualized fall prevention program on fall risk and falls in older people: a randomized, controlled trial." J Am Geriatr Soc **53**(8): 1296-304.
- Lord, S. R. and J. A. Ward (1994). "Age-associated differences in sensori-motor function and balance in community dwelling women." Age Ageing **23**(6): 452-60.
- Lord, S. R., J. A. Ward, et al. (1993). "An epidemiological study of falls in older community-dwelling women: the Randwick falls and fractures study." Aust J Public Health **17**(3): 240-5.
- Lord, S. R., J. A. Ward, et al. (1994). "Physiological factors associated with falls in older community-dwelling women." J Am Geriatr Soc **42**(10): 1110-7.
- Lord, S. R. and I. W. Webster (1990). "Visual field dependence in elderly fallers and non-fallers." Int J Aging Hum Dev **31**(4): 267-77.
- Loughlin, P. J. and M. S. Redfern (2001). "Spectral characteristics of visually induced postural sway in healthy elderly and healthy young subjects." IEEE Trans Neural Syst Rehabil Eng **9**(1): 24-30.
- Luchies, C. W., D. Wallace, et al. (1999). "Effects of age on balance assessment using voluntary and involuntary step tasks." J Gerontol A Biol Sci Med Sci **54**(3): M140-4.
- Lundin-Olsson, L., L. Nyberg, et al. (1997). "'Stops walking when talking' as a predictor of falls in elderly people." Lancet **349**(9052): 617.
- Luukinen, H., K. Koski, et al. (1994). "Incidence rate of falls in an aged population in northern Finland." J Clin Epidemiol **47**(8): 843-50.
- Mackey, D. C. and S. N. Robinovitch (2005). "Postural steadiness during quiet stance does not associate with ability to recover balance in older women." Clin Biomech (Bristol, Avon) **20**(8): 776-83.
- Maki, B. E., A. Zecevic, et al. (2001). "Cognitive demands of executing postural reactions: does aging impede attention switching?" Neuroreport **12**(16): 3583-7.
- Manty, M., A. Heinonen, et al. (2009). "Outdoor and indoor falls as predictors of mobility limitation in older women." Age Ageing **38**(6): 757-61.
- Masud, T. and R. O. Morris (2001). "Epidemiology of falls." Age Ageing **30** Suppl 4: 3-7.
- Mathias, S., U. S. Nayak, et al. (1986). "Balance in elderly patients: the 'get-up and go' test." Arch Phys Med Rehabil **67**(6): 387-9.
- Maurer, C., T. Mergner, et al. (2000). "Vestibular, visual, and somatosensory contributions to human control of upright stance." Neurosci Lett **281**(2-3): 99-102.
- Maylor, E. A. and A. M. Wing (1996). "Age differences in postural stability are increased by additional cognitive demands." J Gerontol B Psychol Sci Soc Sci **51**(3): P143-54.
- McIlroy, W. E. and B. E. Maki (1993). "Do anticipatory postural adjustments precede compensatory stepping reactions evoked by perturbation?" Neurosci Lett **164**(1-2): 199-202.
- McIlroy, W. E. and B. E. Maki (1996). "Age-related changes in compensatory stepping in response to unpredictable perturbations." J Gerontol A Biol Sci Med Sci **51**(6): M289-96.
- Meadmore, K. L., I. E. Dror, et al. (2009). "Lateralisation of spatial processing and age." Laterality **14**(1): 17-29.

- Menant, J. C., R. J. St George, et al. (2010). "Impaired depth perception and restricted pitch head movement increase obstacle contacts when dual-tasking in older people." J Gerontol A Biol Sci Med Sci **65**(7): 751-7.
- Menz, H. B., S. R. Lord, et al. (2003). "Acceleration patterns of the head and pelvis when walking are associated with risk of falling in community-dwelling older people." J Gerontol A Biol Sci Med Sci **58**(5): M446-52.
- Merchant, S. N., L. Velazquez-Villasenor, et al. (2000). "Temporal bone studies of the human peripheral vestibular system. Normative vestibular hair cell data." Ann Otol Rhinol Laryngol Suppl **181**: 3-13.
- Muir, S. W., K. Berg, et al. (2008). "Use of the Berg Balance Scale for predicting multiple falls in community-dwelling elderly people: a prospective study." Phys Ther **88**(4): 449-59.
- Murphy, J. and B. Isaacs (1982). "The post-fall syndrome. A study of 36 elderly patients." Gerontology **28**(4): 265-70.
- Murray, K. J., K. Hill, et al. (2005). "A pilot study of falls risk and vestibular dysfunction in older fallers presenting to hospital emergency departments." Disabil Rehabil **27**(9): 499-506.
- Myers, A. M., L. E. Powell, et al. (1996). "Psychological indicators of balance confidence: relationship to actual and perceived abilities." J Gerontol A Biol Sci Med Sci **51**(1): M37-43.
- Nashner, L. M., F. O. Black, et al. (1982). "Adaptation to altered support and visual conditions during stance: patients with vestibular deficits." J Neurosci **2**(5): 536-44.
- Neider, M. B., J. G. Gaspar, et al. (2011). "Walking and talking: dual-task effects on street crossing behavior in older adults." Psychol Aging **26**(2): 260-8.
- Neurocom, I. I. (1999). The sensory organization test. Equitest system Version 7.0 Data Interpretation Manual.
- Nevitt, M. C., S. R. Cummings, et al. (1991). "Risk factors for injurious falls: a prospective study." J Gerontol **46**(5): M164-70.
- Nevitt, M. C., S. R. Cummings, et al. (1989). "Risk factors for recurrent nonsyncopal falls. A prospective study." JAMA **261**(18): 2663-8.
- NICE (2004). Clinical practice guideline for the assessment and prevention of falls in older people, Royal College of Nursing.
- O'Loughlin, J. L., Y. Robitaille, et al. (1993). "Incidence of and risk factors for falls and injurious falls among the community-dwelling elderly." Am J Epidemiol **137**(3): 342-54.
- O'Neill, T. W., J. Varlow, et al. (1995). "Fall frequency and incidence of distal forearm fracture in the UK." J Epidemiol Community Health **49**(6): 597-8.
- Office for National Statistics (2012). National Population Projections, 2010-based reference volume: Series PP2.
- Oghalai, J. S., S. Manolidis, et al. (2000). "Unrecognized benign paroxysmal positional vertigo in elderly patients." Otolaryngol Head Neck Surg **122**(5): 630-4.
- Okada, S., K. Hirakawa, et al. (2001). "Age-related differences in postural control in humans in response to a sudden deceleration generated by postural disturbance." Eur J Appl Physiol **85**(1-2): 10-8.
- Papaioannou, A., W. Parkinson, et al. (2004). "Prediction of falls using a risk assessment tool in the acute care setting." BMC Med **2**: 1.
- Park, D. C., G. Lautenschlager, et al. (2002). "Models of visuospatial and verbal memory across the adult life span." Psychol Aging **17**(2): 299-320.
- Parnes, L. S., S. K. Agrawal, et al. (2003). "Diagnosis and management of benign paroxysmal positional vertigo (BPPV)." CMAJ **169**(7): 681-93.
- Patten, C., F. B. Horak, et al. (2003). "Head and body center of gravity control strategies: adaptations following vestibular rehabilitation." Acta Otolaryngol **123**(1): 32-40.

- Pavlou, M., R. A. Davies, et al. (2006). "The assessment of increased sensitivity to visual stimuli in patients with chronic dizziness." J Vestib Res **16**(4-5): 223-31.
- Pavlou, M., A. Lingeswaran, et al. (2004). "Simulator based rehabilitation in refractory dizziness." J Neurol **251**(8): 983-95.
- Pavlou, M., C. Quinn, et al. (2011). "The effect of repeated visual motion stimuli on visual dependence and postural control in normal subjects." Gait Posture **33**(1): 113-8.
- Peterka, R. J. (2002). "Sensorimotor integration in human postural control." J Neurophysiol **88**(3): 1097-118.
- Peterka, R. J. and F. O. Black (1990). "Age-related changes in human posture control: sensory organization tests." J Vestib Res **1**(1): 73-85.
- Podsiadlo, D. and S. Richardson (1991). "The timed "Up & Go": a test of basic functional mobility for frail elderly persons." J Am Geriatr Soc **39**(2): 142-8.
- Pothula, V. B., F. Chew, et al. (2004). "Falls and vestibular impairment." Clin Otolaryngol Allied Sci **29**(2): 179-82.
- Powell, L. E. and A. M. Myers (1995). "The Activities-specific Balance Confidence (ABC) Scale." J Gerontol A Biol Sci Med Sci **50A**(1): M28-34.
- Prudham, D. and J. G. Evans (1981). "Factors associated with falls in the elderly: a community study." Age Ageing **10**(3): 141-6.
- Rauch, S. D. (2001). "Vestibular histopathology of the human temporal bone. What can we learn?" Ann N Y Acad Sci **942**: 25-33.
- Redfern, M. S., J. R. Jennings, et al. (2001). "Attention influences sensory integration for postural control in older adults." Gait Posture **14**(3): 211-6.
- Reilly, B. (1990). Dizziness. Clinical Methods: The History, Physical, and Laboratory Examinations. 3rd edition. Walker HK, Hall WD and Hurst JW. Boston, Butterworths.
- Robertson, M. C., A. J. Campbell, et al. (2002). "Preventing injuries in older people by preventing falls: a meta-analysis of individual-level data." J Am Geriatr Soc **50**(5): 905-11.
- Robertson, M. C., N. Devlin, et al. (2001). "Effectiveness and economic evaluation of a nurse delivered home exercise programme to prevent falls. 1: Randomised controlled trial." BMJ **322**(7288): 697-701.
- Robertson, M. C., M. M. Gardner, et al. (2001). "Effectiveness and economic evaluation of a nurse delivered home exercise programme to prevent falls. 2: Controlled trial in multiple centres." BMJ **322**(7288): 701-4.
- Robinet, C. S. and M. A. Vondran (1988). "Functional ambulation velocity and distance requirements in rural and urban communities. A clinical report." Phys Ther **68**(9): 1371-3.
- Rubenstein, L. Z. (2006). "Falls in older people: epidemiology, risk factors and strategies for prevention." Age Ageing **35 Suppl 2**: ii37-ii41.
- Salminen, M., T. Vahlberg, et al. (2009). "The long-term effect of a multifactorial fall prevention programme on the incidence of falls requiring medical treatment." Public Health **123**(12): 809-13.
- Salva, A., I. Bolibar, et al. (2004). "Incidence and consequences of falls among elderly people living in the community." Med Clin (Barc) **122**(5): 172-6.
- Schenkman, M., M. A. Hughes, et al. (1996). "The relative importance of strength and balance in chair rise by functionally impaired older individuals." J Am Geriatr Soc **44**(12): 1441-6.
- Scuffham, P., S. Chaplin, et al. (2003). "Incidence and costs of unintentional falls in older people in the United Kingdom." J Epidemiol Community Health **57**(9): 740-4.
- Shepard, N. T. and S. A. Telian (1995). "Programmatic vestibular rehabilitation." Otolaryngol Head Neck Surg **112**(1): 173-82.

- Sherrington, C., A. Tiedemann, et al. (2011). "Exercise to prevent falls in older adults: an updated meta-analysis and best practice recommendations." N S W Public Health Bull **22**(3-4): 78-83.
- Shumway-Cook A and Woollacott M (1995). Motor Control Theory and Applications, Williams & Wilkins, Baltimore.
- Shumway-Cook, A., M. Baldwin, et al. (1997). "Predicting the probability for falls in community-dwelling older adults." Phys Ther **77**(8): 812-9.
- Shumway-Cook, A., S. Brauer, et al. (2000). "Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test." Phys Ther **80**(9): 896-903.
- Shumway-Cook, A., M. Woollacott, et al. (1997). "The effects of two types of cognitive tasks on postural stability in older adults with and without a history of falls." J Gerontol A Biol Sci Med Sci **52**(4): M232-40.
- Shupert, C. L. and F. B. Horak (1996). "Effects of vestibular loss on head stabilization in response to head and body perturbations." J Vestib Res **6**(6): 423-37.
- Silsupadol, P., V. Lugade, et al. (2009). "Training-related changes in dual-task walking performance of elderly persons with balance impairment: a double-blind, randomized controlled trial." Gait Posture **29**(4): 634-9.
- Silsupadol, P., K. C. Siu, et al. (2006). "Training of balance under single- and dual-task conditions in older adults with balance impairment." Phys Ther **86**(2): 269-81.
- Siu, K. C., L. S. Chou, et al. (2009). "Attentional mechanisms contributing to balance constraints during gait: the effects of balance impairments." Brain Res **1248**: 59-67.
- Siu, K. C. and M. H. Woollacott (2007). "Attentional demands of postural control: the ability to selectively allocate information-processing resources." Gait Posture **25**(1): 121-6.
- Skelton, D. and S. Dinan (1999). "Exercise for falls management: Rationale for an exercise programme aimed at reducing postural instability." Physiotherapy Theory and Practise **15**: 105-20.
- Skelton, D., S. Dinan, et al. (2005). "Tailored group exercise (Falls Management Exercise -- FaME) reduces falls in community-dwelling older frequent fallers (an RCT)." Age Ageing **34**(6): 636-9.
- Sparto, P. J., J. M. Furman, et al. (2006). "Head sway response to optic flow: effect of age is more important than the presence of unilateral vestibular hypofunction." J Vestib Res **16**(3): 137-45.
- Stalenhoef, P. A., J. P. Diederiks, et al. (2002). "A risk model for the prediction of recurrent falls in community-dwelling elderly: a prospective cohort study." J Clin Epidemiol **55**(11): 1088-94.
- Stevens, K. N., I. A. Lang, et al. (2008). "Epidemiology of balance and dizziness in a national population: findings from the English Longitudinal Study of Ageing." Age Ageing **37**(3): 300-5.
- Sturnieks, D. L., R. St George, et al. (2008). "Effects of spatial and nonspatial memory tasks on choice stepping reaction time in older people." J Gerontol A Biol Sci Med Sci **63**(10): 1063-8.
- Sturnieks, D. L., R. St George, et al. (2008). "Balance disorders in the elderly." Neurophysiol Clin **38**(6): 467-78.
- Sundermier, L., M. H. Woollacott, et al. (1996). "Postural sensitivity to visual flow in aging adults with and without balance problems." J Gerontol A Biol Sci Med Sci **51**(2): M45-52.
- Szabo, S. M., P. A. Janssen, et al. (2008). "Older women with age-related macular degeneration have a greater risk of falls: a physiological profile assessment study." J Am Geriatr Soc **56**(5): 800-7.

- Talbot, L. A., R. J. Musiol, et al. (2005). "Falls in young, middle-aged and older community dwelling adults: perceived cause, environmental factors and injury." BMC Public Health **5**: 86.
- Teasdale, N. and M. Simoneau (2001). "Attentional demands for postural control: the effects of aging and sensory reintegration." Gait Posture **14**(3): 203-10.
- Tinetti, M. E. (1986). "Performance-oriented assessment of mobility problems in elderly patients." J Am Geriatr Soc **34**(2): 119-26.
- Tinetti, M. E., D. I. Baker, et al. (1994). "A multifactorial intervention to reduce the risk of falling among elderly people living in the community." N Engl J Med **331**(13): 821-7.
- Tinetti, M. E., M. Speechley, et al. (1988). "Risk factors for falls among elderly persons living in the community." N Engl J Med **319**(26): 1701-7.
- Tinetti, M. E. and C. S. Williams (1997). "Falls, injuries due to falls, and the risk of admission to a nursing home." N Engl J Med **337**(18): 1279-84.
- Tinetti, M. E., C. S. Williams, et al. (2000). "Dizziness among older adults: a possible geriatric syndrome." Ann Intern Med **132**(5): 337-44.
- Toulotte, C., A. Thevenon, et al. (2006). "Identification of healthy elderly fallers and non-fallers by gait analysis under dual-task conditions." Clin Rehabil **20**(3): 269-76.
- Turner, G. R. and R. N. Spreng (2011). "Executive functions and neurocognitive aging: dissociable patterns of brain activity." Neurobiol Aging.
- Uneri, A. and S. Polat (2008). "Vertigo, dizziness and imbalance in the elderly." J Laryngol Otol **122**(5): 466-9.
- Van Impe, A., J. P. Coxon, et al. (2011). "Age-related changes in brain activation underlying single- and dual-task performance: visuomanual drawing and mental arithmetic." Neuropsychologia **49**(9): 2400-9.
- Verghese, J., C. Wang, et al. (2011). "Relationship of clinic-based gait speed measurement to limitations in community-based activities in older adults." Arch Phys Med Rehabil **92**(5): 844-6.
- Vogler, C. M., C. Sherrington, et al. (2009). "Reducing risk of falling in older people discharged from hospital: a randomized controlled trial comparing seated exercises, weight-bearing exercises, and social visits." Arch Phys Med Rehabil **90**(8): 1317-24.
- von Brevern, M., A. Radtke, et al. (2007). "Epidemiology of benign paroxysmal positional vertigo: a population based study." J Neurol Neurosurg Psychiatry **78**(7): 710-5.
- Voukelatos, A., R. G. Cumming, et al. (2007). "A randomized, controlled trial of tai chi for the prevention of falls: the Central Sydney tai chi trial." J Am Geriatr Soc **55**(8): 1185-91.
- Vouriot, A., G. C. Gauchard, et al. (2004). "Sensorial organisation favouring higher visual contribution is a risk factor of falls in an occupational setting." Neurosci Res **48**(3): 239-47.
- Walther, L. E. and M. Westhofen (2007). "Presbyvertigo-aging of otoconia and vestibular sensory cells." J Vestib Res **17**(2-3): 89-92.
- Whitney, J. C., S. R. Lord, et al. (2005). "Streamlining assessment and intervention in a falls clinic using the Timed Up and Go Test and Physiological Profile Assessments." Age Ageing **34**(6): 567-71.
- Whitney, S. L., M. T. Hudak, et al. (2000). "The dynamic gait index relates to self-reported fall history in individuals with vestibular dysfunction." J Vestib Res **10**(2): 99-105.
- Whitney, S. L., G. F. Marchetti, et al. (2004). "The sensitivity and specificity of the Timed "Up & Go" and the Dynamic Gait Index for self-reported falls in persons with vestibular disorders." J Vestib Res **14**(5): 397-409.

- Whitney, S. L., G. F. Marchetti, et al. (2006). "The relationship between falls history and computerized dynamic posturography in persons with balance and vestibular disorders." Arch Phys Med Rehabil **87**(3): 402-7.
- Whitney, S. L. and P. J. Sparto (2011). "Principles of vestibular physical therapy rehabilitation." Neurorehabilitation **29**(2): 157-166.
- Whitney, S. L., D. M. Wrisley, et al. (2002). "The effect of age on vestibular rehabilitation outcomes." Laryngoscope **112**(10): 1785-90.
- Williams, S. B., C. A. Brand, et al. (2010). "Feasibility and outcomes of a home-based exercise program on improving balance and gait stability in women with lower-limb osteoarthritis or rheumatoid arthritis: a pilot study." Arch Phys Med Rehabil **91**(1): 106-14.
- Winter, D. A., C. D. MacKinnon, et al. (1993). "An integrated EMG/biomechanical model of upper body balance and posture during human gait." Prog Brain Res **97**: 359-67.
- Woollacott, M. and A. Shumway-Cook (2002). "Attention and the control of posture and gait: a review of an emerging area of research." Gait Posture **16**(1): 1-14.
- Woollacott, M. and T. Vander Velde (2008). "Non-visual spatial tasks reveal increased interactions with stance postural control." Brain Res **1208**: 95-102.
- Wrisley, D. M. and N. A. Kumar (2010). "Functional gait assessment: concurrent, discriminative, and predictive validity in community-dwelling older adults." Phys Ther **90**(5): 761-73.
- Wrisley, D. M., G. F. Marchetti, et al. (2004). "Reliability, internal consistency, and validity of data obtained with the functional gait assessment." Phys Ther **84**(10): 906-18.
- Wrisley, D. M., M. L. Walker, et al. (2003). "Reliability of the dynamic gait index in people with vestibular disorders." Arch Phys Med Rehabil **84**(10): 1528-33.
- Yang, X. J., K. Hill, et al. (2012). "Effectiveness of a targeted exercise intervention in reversing older people's mild balance dysfunction: a randomized controlled trial." Phys Ther **92**(1): 24-37.
- Yardley, L. (2004). "Fear of falling: links between imbalance and anxiety." Reviews in Clinical Gerontology **13**: 195-201.
- Yardley, L., M. Donovan-Hall, et al. (2004). "Effectiveness of primary care-based vestibular rehabilitation for chronic dizziness." Ann Intern Med **141**(8): 598-605.
- Yardley, L., E. Masson, et al. (1992). "Symptoms, anxiety and handicap in dizzy patients: development of the vertigo symptom scale." J Psychosom Res **36**(8): 731-41.
- Yogev-Seligmann, G., J. M. Hausdorff, et al. (2008). "The role of executive function and attention in gait." Mov Disord **23**(3): 329-42; quiz 472.
- Zigmond, A. S. and R. P. Snaith (1983). "The hospital anxiety and depression scale." Acta Psychiatr Scand **67**(6): 361-70.
- Zur, O. B., YN. Carmeli, E. (2006). "Correlation between vestibular function and hip fracture following falls in the elderly: a case-controlled study." Physiotherapy **92**: 208-213.

Appendix 1. Bimodal spatial multi-tasking significantly increases response times in healthy adults

Participants

A convenience sample of ten subjects (mean age 38.1, range: 26-61) with no evidence of balance impairment, colour blindness or hearing loss were recruited from the centre of human and aerospace physiological sciences, King's College London into this developmental study. As this study was performed to test a novel protocol and was a proof of concept study local research ethics approval was not required.

Experimental apparatus and techniques

A modified video game dance mat measuring 92cm by 81cm containing four touch sensitive colored squares (16cm x 16cm) placed anteriorly, posteriorly and medio-laterally of a central square (22cm x 22cm), was used to measure reactive step response times for the visual coded spatial task (Fig.1).



Figure 1: Experimental set up for the multi-task test

Task ordering

The three tasks were performed independently (single visuo-spatial, single audio-verbal and single audio-spatial). The two auditory tasks were also independently combined with the visuo-spatial task for the bi-modal dual-task paradigm. Task sequence was randomised to reduce order and learning effects. Practise trials were not performed, as this test intended to determine an individual's response to a novel sensory integration challenge.

Visual Coded Spatial Task (VST) (Stepping task)

Subjects stood barefoot in the mat's centre with feet hip-width apart looking ahead at a computer display (39cm diagonally corner to corner) display placed 80cm away at waist height. When the display changed color, subjects were instructed to step as quickly and safely as possible with one foot onto the corresponding colored square on the mat and then return the foot to the original position within the centre square and await the next screen color change. Screen color changes occurred quasi-randomly every 3.5 to 6 seconds so that seven steps in total were performed per condition. Stimulus presentation was randomized for both step direction (anterior, posterior, and lateral) and time, but at least one step was performed in each direction per condition. After each trial the mat was rotated 90° clockwise to negate any learning effect from prior knowledge of the color square positions. Each condition lasted 30 seconds.

Auditory Coded tasks

Two auditory tasks were provided, one verbally loaded and the other spatially loaded. The auditory tasks utilized a stroop design presented through wireless stereo headphones with both tasks deemed to be of similar difficulty (Barra et al. 2006; Green et al. 2010). The subject was required to respond to the auditory stimulus by pressing one of two buttons on a hand held keypad depending on congruency of responses. If the response was congruous a button with a "tick" symbol was to be pressed and if incongruent a button with a "cross" symbol was to be pressed. A new stimulus was

presented 2 seconds after the subject had responded to the previous stimulus. If after 4 seconds the subject had not responded, the question was timed out, an incorrect score was recorded and a new stimulus was presented.

Auditory Coded Verbal Task (AVT)

The verbal task required the subject to respond to monosyllabic male or female names spoken by either a male or a female voice delivered by stereo headphones. Names were randomly selected for gender from a selection of 40 common names, with speaking voice gender randomly selected. If the gender of the voice and name matched (i.e. male voice speaking the name “John”) then the stimuli were congruent, if they did not match (i.e. female voice speaking the name “John”) the stimuli were incongruent.

Auditory Coded Spatial Task (AST)

For the spatial task subjects were required to respond to unilateral aural stimuli by pressing one of two buttons (tick / cross) on a handheld wireless keypad. The stimuli consisted of the words “Left” and “Right” delivered through either the left or right headphone speaker. If the word matched the side it was presented to (i.e. “Left” in the left ear) the result was congruous and incongruous if the word did not match the side (i.e. “right” in the left ear). Word order and side of presentation were randomly assigned.

Data Recording

Three custom programs were utilised to provide the 1) auditory stimuli (Barra et al. 2006; Green et al. 2010), 2) the visual stimulus and 3) analysis of raw response data for the visual stimulus. Programmes for the visual stimulus were developed in Matlab 7.4 (MathWorks, Natick, MA).

Responses were detected as either a button press on a hand held keypad (auditory task), or a step surpassing a pressure threshold on the touch sensitive mat (visuo-spatial task). For the auditory tasks response time and accuracy were recorded via the custom programme and outputted as an RTF file for analysis. The response time from the visuo-spatial task was computed and the algorithm subsequently determined if the response given was the correct one. If the subject did not provide any response, the maximum time for that particular section was taken and the response was automatically rated as inaccurate. A Labjack U3 (Labjack Corporation, Lakewood, Colorado, USA) analogue to digital converter (sample rate 200Hz) was used to integrate the mat with the recording PC.

Statistical Analysis

Statistical analysis was performed using SPSS version 17 (SPSS Inc, Chicago, Ill). Mean and standard deviation are presented for response time and accuracy. Data was non-normally distributed, therefore it was base-10 log transformed prior to ANOVA analysis. A one-way ANOVA with Bonferroni adjusted post-hoc analysis was used to assess the effect of task type (single task, Dual AVT, Dual AST) on step response time and accuracy. Effect size

for the ANOVA was determined by calculating η^2 using the equation (Field 2005):

$$\eta^2 = \frac{\text{Sum of Squares Between}}{\text{Sum of Squares Total}}.$$

Paired t tests were used to assess differences between the single and dual task response time and accuracy for the auditory tasks. Effect sizes were calculated using the formula (Field 2005):

$$r = \sqrt{\frac{t^2}{t^2 + df}}$$

Dual-task costs (DTC) i.e. the percentage change in response time and response accuracy due to the dual-task condition were calculated for both response time and response accuracy for the auditory coded spatial task and visually coded spatial task using the following equation (Menant et al. 2010; Van Impe et al. 2011):

$$\text{Dual task cost (\%)} = \frac{(\text{Dual task} - \text{Single task})}{\text{Single task}} * 100$$

Positive DTC values indicate either an increase in response time or accuracy in the dual-task condition. Within-group differences in DTC were assessed using the Wilcoxon signed rank test as data was non-normally distributed and could not undergo transformation due to negative values. Pearson's Rho

was calculated to determine the effect size of the difference between DTC's using the formula (Field 2005)

$$r = \frac{z}{\sqrt{n}}$$

Data are presented as mean \pm standard deviation for response times and accuracy, and median and inter-quartile range for DTC's (Tables 1 and 2). For all tests statistical significance was assumed if $p < .05$.

Results

Step responses to the visual coded spatial task (VST)

There was a significant effect of applying a secondary task to response times ($F(2,27) = 20.471$, $p < .001$, $\eta^2 = 0.6$) Post-hoc analysis identified that dual tasking using the AST significantly increased response times compared to both the single task ($p < .001$) condition and dual tasking using the AVT ($p = .004$). Dual tasking using the AVT significantly increased response time compared to single tasking ($p = .04$) (Figure 2).

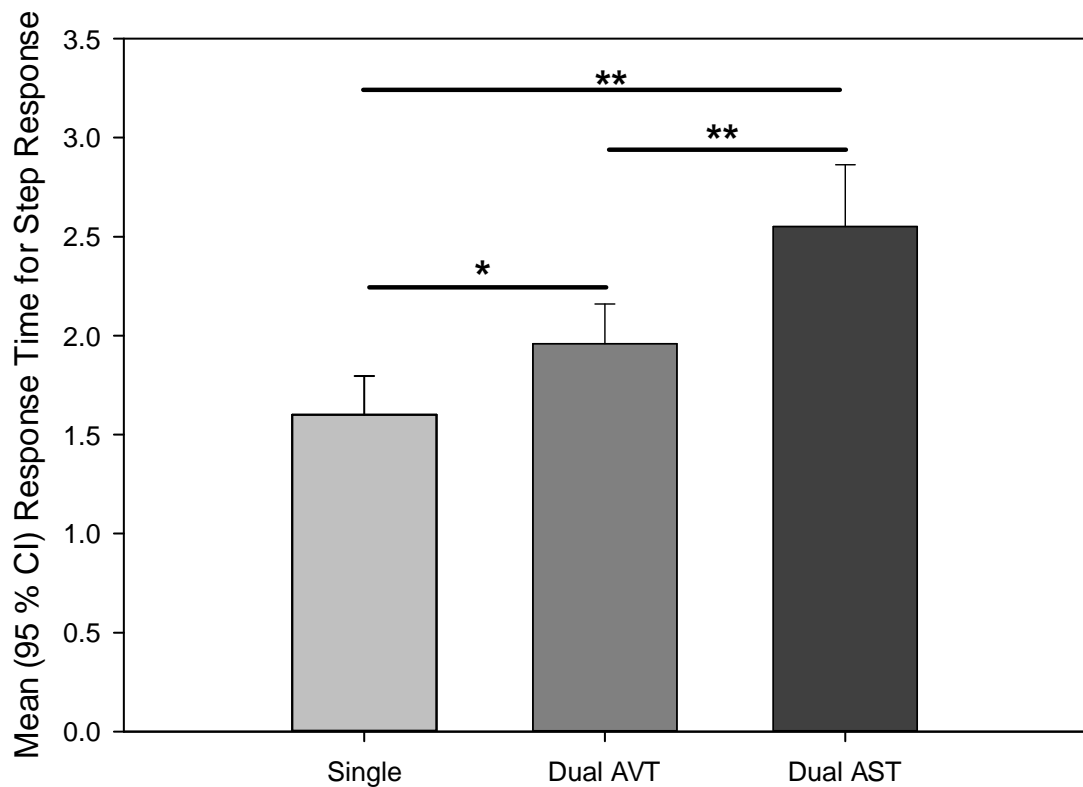


Figure 2: Mean (95% CI) Step response time (s) to the visuo-spatial task (VST) for single and dual task conditions. AVT – Audio-Verbal task, AST – Ausio-Spatial task. */** $p < .05 / .01$

Response accuracy of the VST was significantly affected by adding a secondary task ($F=4.664$, $p=.018$, $\eta^2=0.26$). Post-hoc analysis identified that adding a secondary spatially loaded task (AST) significantly reduced accuracy of responses compared to both the single task condition ($p=.04$) and when dual tasking performing a verbally loaded task (AVT) ($p=.04$). There was no difference in response accuracy between the single task and dual task condition utilising the AVT (Figure 3).

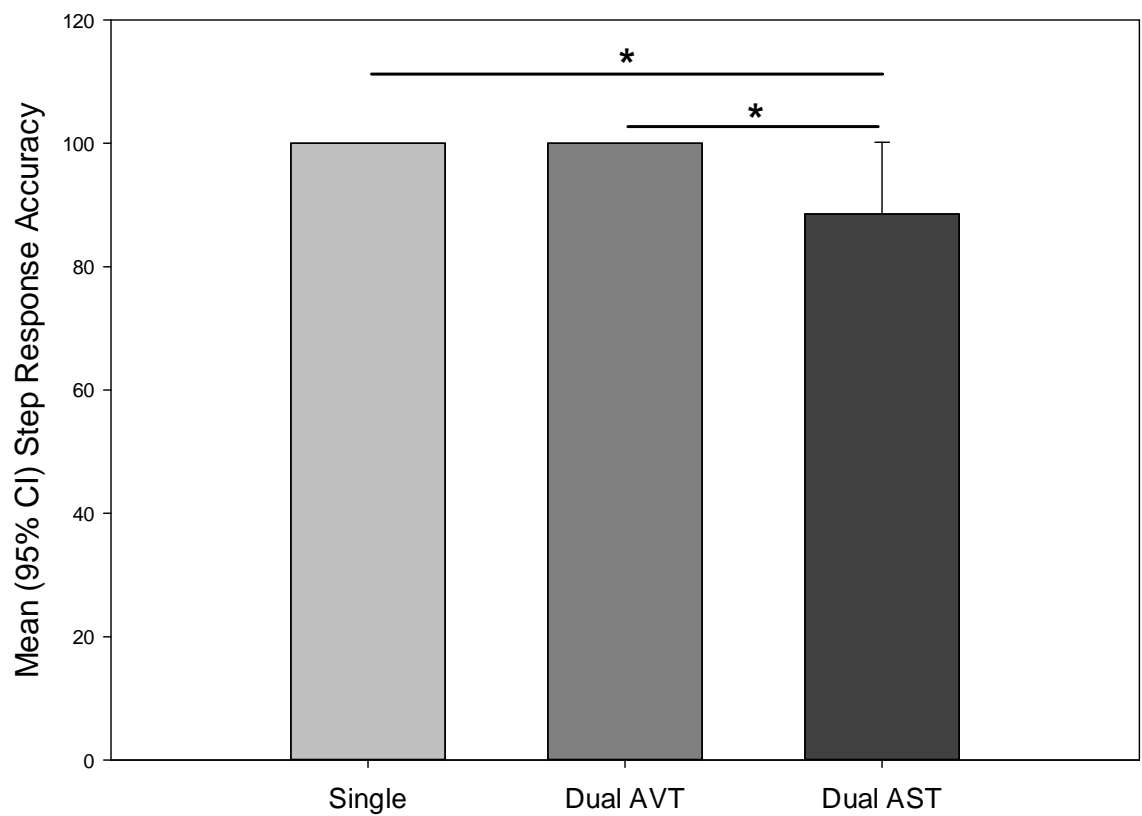


Figure 3: Mean (95% CI) response accuracy (%) for the visuo-spatial task (VST) whilst single tasking and dual tasking performing a concurrent audio-verbal (AVT) or audio-spatial (AST) task. * $P < .05$

The cost of performing the dual task (DTC) was significantly higher in the visuo-spatial task (VST) when coupled with the audio-spatial task (AST), compared to when coupled with the audio-verbal task (AVT) ($p = .008$, $T = 0$, $r = 0.8$) (Figure 4).

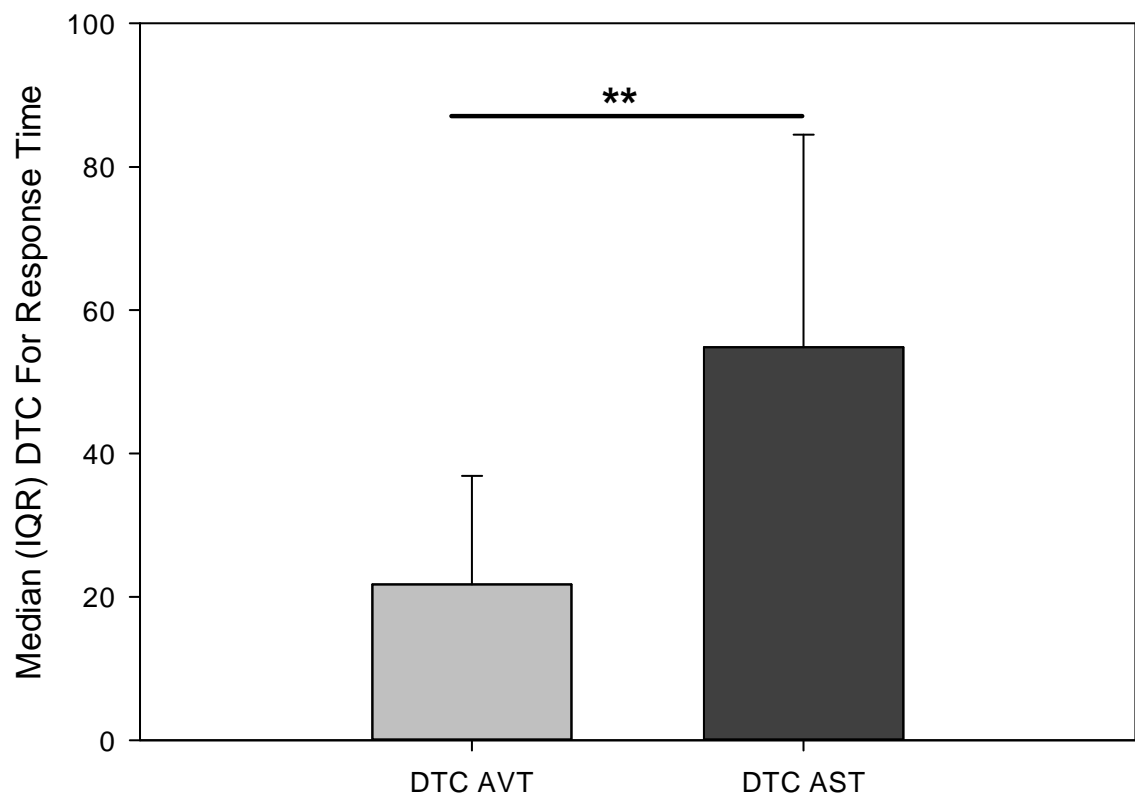


Figure 4: Mean (95% CI) Dual Task Costs for step response time (VST) when combined with either the audio-verbal (AVT) or audio-spatial (AST) tasks

No significant differences in DTC for response accuracy in the VST task were noted according to type of secondary task provided.

	Single Task	Dual Task Verbal	Dual Task Spatial	DTC Verbal	DTC Spatial
Response Time (s)	1.6 (0.27)	1.96 (0.28)*	2.55 (0.44)**‡	21.77 (10.39-33.48)	54.87 (34.7-80.32) ‡
Response Accuracy (%)	100.0 (0)	100.0 (0)	88.56 (16.23)*†	0 (0-0)	0 (-28.6 -0)

Table 1: Response time, accuracy and Dual task costs for the visuo-spatial task in the single and dual task conditions. RT and Accuracy presented as Mean (SD), DTC presented as Median (IQR)

*/ ** significantly different to single task $p < .05 / .01$, †/ ‡ significantly different to Verbal task $p < .05 / .01$, §§ Significantly different to DTC verbal $p < .01$

Responses to the auditory coded tasks

Dual tasking increased response times for both tasks compared to the single task condition (AVT: $t(9) = -2.755$, $p = .022$, $r = 0.67$. AST: $t(9) = -4.902$, $p = .001$, $r = 0.85$). There were no differences between single task response times for the AVT and AST tasks ($p = .453$). Dual task response times for the AST were significantly longer than those for the dual task AVT ($t(9) = -3.6$, $p = .006$, $r = 0.77$) (Figure 5). No differences were noted for response accuracy or dual task costs.

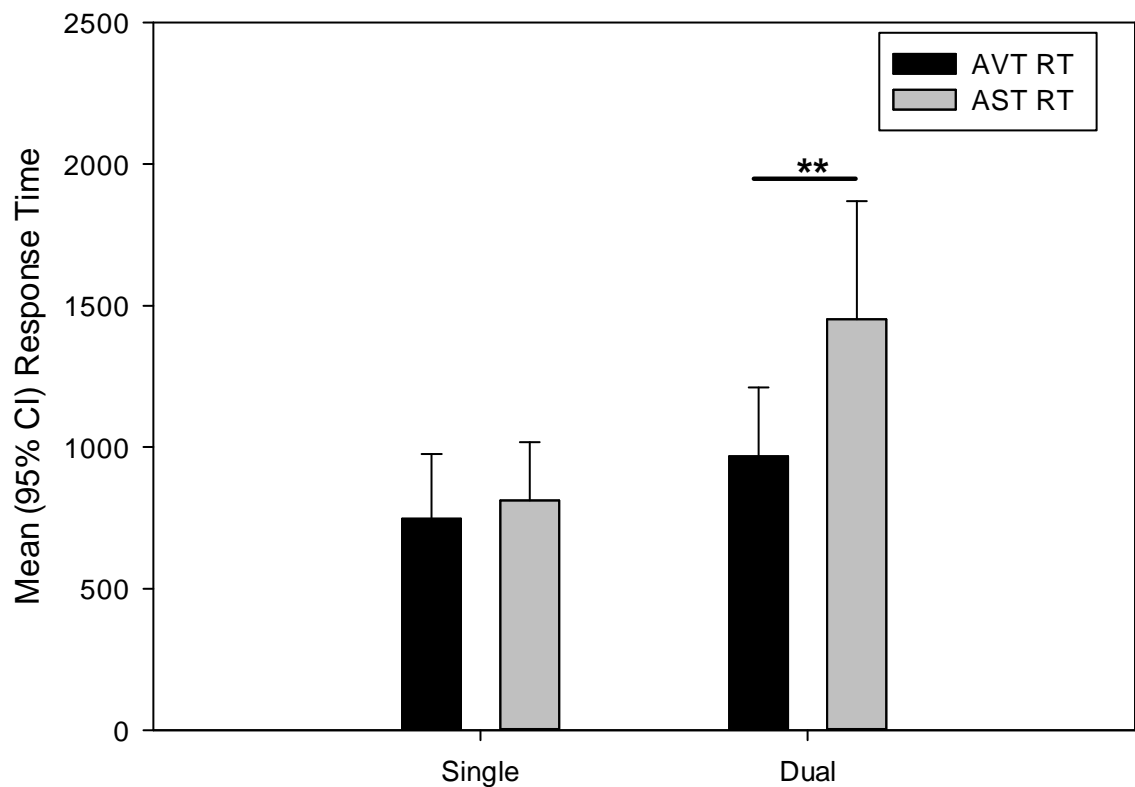


Figure 5: Mean (95% CI) of response time (ms) for auditory tasks in single and dual task conditions.

** $p < .01$.

	Single Task RT (s)	Dual Task RT (s)	DTC RT	Single Task Accuracy (%)	Dual Task Accuracy (%)	DTC Accuracy
AVT	747.22 (319.71)	967.67 (339.95) *	27.12 (-0.67- 70.14)	100.0 (0)	97.21 (6.16)	0 (-2.53-0)
AST	811.65 (287.55)	1452.08 (583.36) **‡	77.11 (24.81- 163.64)	90.62 (14.12)	86.89 (12.34)	0 (-17.88-10.25)

Table 2: Mean (SD) response time and accuracy for the auditory tasks. Median (IQR) DTC for auditory tasks

*/ ** significantly different to single task $p < .05 / .01$, †/ ‡ significantly different to Verbal task (AVT) $p < .05 / .01$

Conclusions

Auditory spatial tasks (AST) significantly impact upon response time and accuracy when combined with a visuo-spatial task, creating significantly greater increases in step response time and reductions in accuracy compared to auditory verbal tasks (AVT). These results are similar to previous studies reporting that spatial tasks have greater impact upon balance (Barra et al. 2006) and volitional directed stepping (Sturnieks et al. 2008) than non spatial tasks. Although this protocol provides additional levels of processing; two cognitive tasks are provided concurrently in the dual task condition, individuals are able to perform concurrent tasks with similar decremental effects observed in simpler paradigms (such as beam balancing or stepping on illuminated panels), and so this approach may be feasible for use in future investigations. Although the sample size is relatively small (n=10) the measured effect sizes are large both for RT and DTC (0.6-0.8).

Volitional step protocols have been shown to be sensitive to predict falls in older adults (Lord and Fitzpatrick 2001), yet the authors believe that current dual task protocols do not represent the complexities of dual task processing evident in normal every-day life, such as road crossing (Dommes and Cavallo 2011; Neider et al. 2011) or navigating through crowds. This paradigm, when utilising the AST and VST may provide a suitably complex protocol to test dual tasking ability in healthy older adults.

Appendix 2. Supplementary data analysis for chapter 3

Data analysis methods

Only correct responses were included in the analysis. Subjects that had $\geq 50\%$ errors for any measure were excluded from the final analysis (younger adults $n=0$, older adults $n=6$). Statistical analysis was performed as described in the main body text.

Results

Response times

The visually coded spatial task (VS) produced significantly longer ($F_{1,27}=12.257$, $p<.01$, $\eta^2=0.312$) response times than the auditory coded spatial task (AS) (

Table 0.1). Task complexity (i.e. single/multi) also had a significant effect on response times ($F_{1,27}=88.276$, $p<.01$, $\eta^2=0.766$), with the complex multi-task condition eliciting longer response times. There were no significant 2-way interactions (task type*age group, task complexity*age group, task type*complexity) however there was a significant 3-way interaction between age group, task type and task complexity ($F_{1,27}=8.759$, $p<.01$, $\eta^2=0.245$) highlighting the fact that age significantly influences this interaction, with older adults increasing response times more than younger adults.

Dual-task costs (DTC) were significantly different between age groups for the VS task, with greater cost noted in the older compared to younger adults ($z=-2.074$, $p<.05$, $r= 0.46$). There was a trend for AS DTC's to be greater in younger adults ($z=-1.933$, $p=.055$, $r= 0.43$). Significant within-group differences were observed between VS and AS DTC's for younger adults ($z=-3.248$, $p<.01$, $r= 0.73$), with AS DTC's greater than VS. No difference in DTC's between AS and VS was observed in older adults ($z=-1.007$, $p=.314$, $r=0.34$) (Figure 0.1).

		Response Time (s)				Response Accuracy (%)			
		Single	Dual	Single	Dual	Single	Dual	Single	Dual
		AS	AS	VS	VS	AS	AS	VS	VS
Younger N=20	Mean	1.22	1.93	1.56	1.84	97.73	86.82	96.67	99.17
	SD	.32	.47	.53	.47	5.00	13.02	6.84	3.73
Older N=9	Mean	1.93	2.50	2.24	3.85	88.89	68.69	90.74	68.52
	SD	.63	.43	.66	1.98	14.21	17.67	14.70	17.57

Table 0.1 Mean (SD) response times (s) and accuracy (%) for single and dual task conditions for younger and older adults with error rates less than 50%

AS = Auditory coded spatial task, VS = Visually coded spatial task

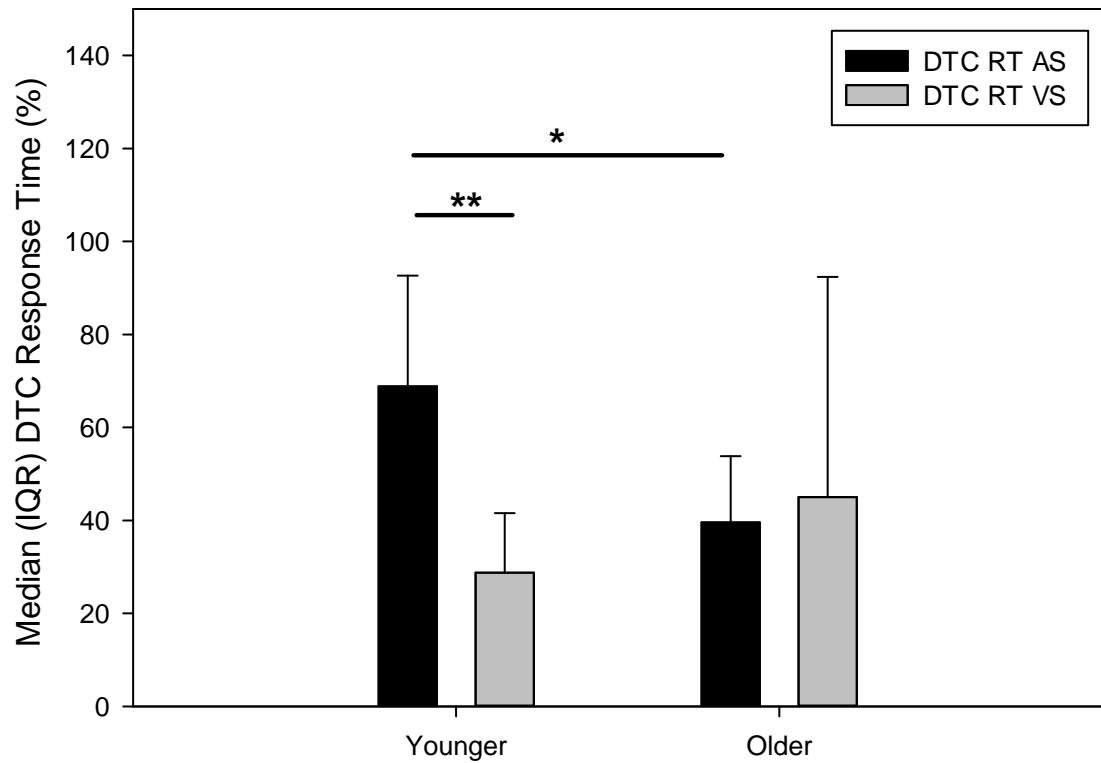


Figure 0.1 Median (IQR) dual task costs (DTC) for response time in the visuo-spatial (VS) and audio-spatial (AS) tasks for younger and older adults. **/ * $p < .05 / .01$

Task Accuracy

Task complexity significantly effects response accuracy with greater accuracy demonstrated during the single task condition ($F_{1,27} = 35.824$, $p < .01$, $\eta^2 = 0.57$) (

Table 0.1). A significant two way interaction was also noted between task complexity and age group for the multi-task condition, whereby accuracy was significantly lower for older adults ($F_{1,27} = 17.66, p < .01, \eta^2 = 0.396$). No other significant interactions were noted.

The DTC for response accuracy during the VS spatial task was significantly different between age groups ($z = -3.806, p < .01, r = 0.85$) with older adults experiencing a greater DTC. There was no significant DTC difference between age groups for the auditory coded spatial task ($z = -1.347, p = .199, r = 0.3$). Significant within-group differences between AS and VS tasks for response accuracy DTC's were observed in younger adults ($z = -2.847, p < .01, \eta^2 = 0.64$) with Highest DTC's for the AS task. No difference between task DTC's was noted for older adults ($z = -0.533, p = .594, r = 0.18$) (Figure 0.2).

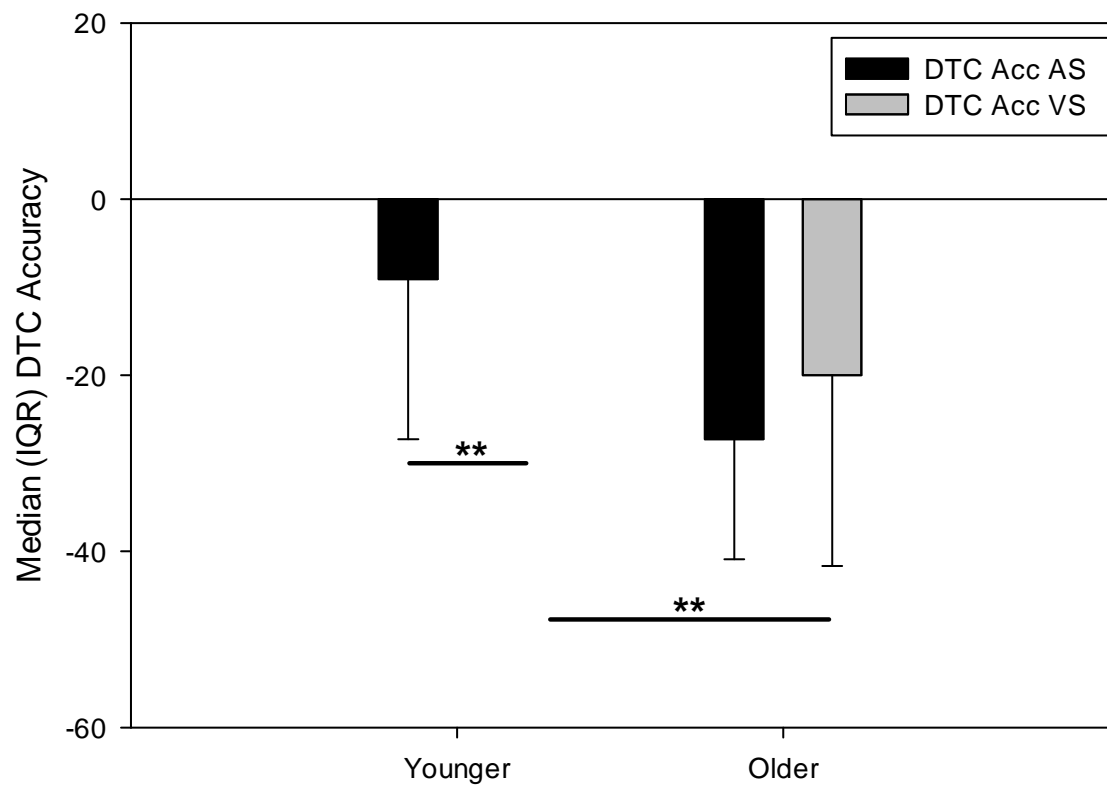


Figure 0.2 Median (IQR) dual task costs (DTC) for response accuracy in the visuo-spatial (VS) and audio-spatial (AS) tasks for younger and older adults. */** $p < .05 / .01$.

Appendix 3. Screening for Dual Processing Study

- 1) Are you living independently at home? Y / N
 2) Do you suffer from Dizziness? Y / N
 3) Have you fallen in the previous 12 months Y/N

Medications

- 1) 2) 3)
 4) 5) 6)

VERTIGO SYMPTOM SCALE

The following questions ask about the type of symptoms you experience and how often they occur. Please circle the appropriate number to indicate about how many times you have experienced each of the symptoms listed below **during the past month.**

0	1	2	3	4
Never	A few times (1-3 times a month)	Several times (4-12 times a month)	Quite often (on average more than 4-7 times a week)	Very often (on average more than once a day)

How often in the past month have you had the following symptoms:

1. A feeling that either you, or things around you, are spinning or moving, lasting (PLEASE ANSWERS ALL THE CATEGORIES)
 - a. Less than 2 minutes 0 1 2 3
 - b. Up to 20 minutes 0 1 2 3
 - c. 20 minutes to one hour 0 1 2 3
 - d. Several hours 0 1 2 3
 - e. More than 12 hours 0 1 2 3

2. Pains in the heart or chest region

0 1 2 3 4

3. Hot or cold spells

0 1 2 3 4

4. Unsteadiness so severe that you actually fall

0 1 2 3 4

5. Nausea (feeling sick), stomach churning

0 1 2 3 4

6. Tension/soreness in your muscles

0 1 2 3 4

7. A feeling of being light-headed, 'swimmy' or giddy, lasting
(PLEASE ANSWERS ALL THE CATEGORIES)

- | | | | | | |
|----|------------------------|---|---|---|---|
| a. | Less than 2 minutes | 0 | 1 | 2 | 3 |
| b. | Up to 20 minutes | 0 | 1 | 2 | 3 |
| c. | 20 minutes to one hour | 0 | 1 | 2 | 3 |
| d. | Several hours | 0 | 1 | 2 | 3 |
| e. | More than 12 hours | 0 | 1 | 2 | 3 |

8. Trembling, shivering

0 1 2 3 4

9. Feeling of pressure in the ear(s)

0 1 2 3 4

10. Heart pounding or fluttering

0 1 2 3 4

11. Vomiting

0 1 2 3 4

12. Heavy feeling in arms or legs

0 1 2 3 4

13. Visual disturbances (e.g. blurring, flickering, spots before the eyes)

0 1 2 3 4

14. Headache or feeling of pressure in the head

0 1 2 3 4

15. Unable to stand or walk properly without support

0 1 2 3 4

16. Difficulty in breathing, short of breath

0 1 2 3 4

17. Loss of concentration or memory

0 1 2 3 4

18. Feeling unsteady, about to lose balance lasting:

(PLEASE ANSWER ALL THE CATEGORIES)

- | | | | | | |
|----|------------------------|---|---|---|---|
| a. | Less than 2 minutes | 0 | 1 | 2 | 3 |
| b. | Up to 20 minutes | 0 | 1 | 2 | 3 |
| c. | 20 minutes to one hour | 0 | 1 | 2 | 3 |
| d. | Several hours | 0 | 1 | 2 | 3 |

e.	More than 12 hours	0	1	2	3	4
----	--------------------	---	---	---	---	---

19. Tingling, prickling or numbness in parts of the body

20. Pains in the lower part of your back

21. Excessive sweating

22. Feeling faint, about to black out

Appendix 4. INFORMATION SHEET FOR PARTICIPANTS

REC Reference Number: BDM/10/11-42

YOU WILL BE GIVEN A COPY OF THIS INFORMATION SHEET

A comparison between healthy older adults and younger individuals in performance of a novel dual processing test: A pilot study.

We would like to invite you to participate in this original research project. This study is being carried out as part of a larger PhD study by Matthew Liston of King's College London. You should only participate if you want to; choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, it is important for you to understand why the research is being done and what your participation will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

Background

Many studies have been carried out to assess the effect of performing a cognitive "thinking" task on balance. It has been demonstrated that cognitive and balance tasks can interfere with each other; especially with advancing years. There are a number of theories as to why this may occur, including competition for resources in the brain and ability to divert attention between the two tasks.

What is the purpose of this study?

The purpose of this study is to determine the effect of processing two simultaneous cognitive tasks on a person's ability to perform a directed stepping test. This pilot study will analyse the effect of age on the ability to perform these tasks.

Do I have to take part?

It is up to you to decide whether to take part. If you agree to participate we will ask you to give your verbal consent and sign a consent form to show that you have agreed to take part. You are free to withdraw at any time without giving a reason.

What will happen to me if I take part?

If you decide to participate, you will be asked to fill out a brief screening questionnaire with the researcher. This will take approximately 5 minutes. If at this

point you do not meet the inclusion criteria for the study no further participation will be required and the questionnaire will be disposed of in a confidential waste bin at King's College London. If you are appropriate for this study you will be invited to attend the research laboratory at King's College London for a single testing session. Travel expenses to and from the research site will be reimbursed on presentation of a valid receipt for your travel.

On the day of testing you will have the study described to you and will be given this information sheet to read again. You will then be asked to sign a consent form if you decide to participate. You will then be asked to perform the stepping test with and without a second cognitive task, and the cognitive tests on their own. The cognitive task requires you to press buttons on a handheld key pad in response to words spoken into your ears through headphones. The stepping task requires you to stand on a mat and take a single step forward / left / right / backward onto a coloured marker in response to a change in screen colour. You will be required to take 7 steps in each trial and there are 5 trials.

Are there any risks to me from taking part?

You may, on occasions feel slightly unsteady whilst performing the test. A Physiotherapist will be supervising you very closely at all times and will provide assistance if necessary.

Will my taking part be kept confidential?

All information that is collected about you during the course of this research will be kept strictly confidential. All information for this project will be stored on password protected computers used only by research staff. We would like to keep anonymised copies of the results for use in future studies by researchers at King's College London.

What happens if there is a problem?

This study has been reviewed by the Biomedical & Health Sciences, Dentistry, Medicine and Natural & Mathematical Sciences Research Ethics Subcommittee at King's College London. The researchers in charge of this investigation are Dr. Marousa Pavlou (Lecturer in Physiotherapy, King's College London) and Mr. Matthew Liston (Physiotherapist, PhD student at King's College London).

If you have any concerns regarding the study please contact Mr. Matthew Liston, the physiotherapist who will be conducting the test who will try to answer your

questions. If you are unhappy and wish to complain formally, you can do this through either Dr Marousa Pavlou, Mr Matthew Liston or through the King's College London Research Ethics Committee.

It is up to you to decide whether to take part or not. If you decide to take part you are still free to withdraw at any time and without giving a reason. You may withdraw your data from the project at any time up until it is transcribed for use in the final report which is the 1st June 2011.

If this study has harmed you in any way you can contact King's College London using the details below for advice and information

Matthew Liston

Division of Applied Biomedical Research

Room 3.11 Shepherd's House

Guy's Campus

King's College London

London Bridge

SE1 1UL

Tel: 0207 838 6679

Email: matthew.liston@kcl.ac.uk

CONSENT FORM FOR PARTICIPANTS IN RESEARCH STUDIES

Please complete this form after you have read the Information Sheet and/or listened to an explanation about the research.



Title of Study: A comparison between healthy older adults and younger individuals in performance of a novel dual processing test: A pilot study.

King's College Research Ethics Committee Ref: _____

- Thank you for considering taking part in this research. The person organising the research must explain the project to you before you agree to take part.
- If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you decide whether to join in. You will be given a copy of this Consent Form to keep and refer to at any time.
- I understand that if I decide at any time during the research that I no longer wish to participate in this project, I can notify the researchers involved and withdraw from it immediately without giving any reason. Furthermore, I understand that I will be able to withdraw my data up to the point of publication or up until the point stated on the Information Sheet).
- I consent to the processing of my personal information for the purposes explained to me. I understand that such information will be handled in accordance with the terms of the Data Protection Act 1998.

Participant's Statement:

I _____

agree that the research project named above has been explained to me to my satisfaction and I agree to take part in the study. I have read both the notes written above and the Information Sheet about the project, and understand what the research study involves.

Signed

Date

Appendix 5. Instructions for bi-modal spatial multi task test

General test instructions

You will be asked to perform 3 tests for this study, consisting of a stepping task and a cognitive task. For each test you will be required to stand on the central square of the mat looking directly ahead to the screen in front of you. You will be required to wear a pair of headphones and hold a keypad for each test. There are two separate tests that will be performed on their own and combined with each other. I will provide instructions for each test prior to them starting.

The stepping test will require you to watch the computer screen in front of you. When the screen changes colour step with the nearest foot to the corresponding colour on the mat. The test will require a proper step, so that your weight is transferred onto the stepping foot, and not a tap. This test measures the accuracy of your response and the time it takes to respond. If you step onto the wrong colour you will receive the maximum time penalty, so ensure that you step into the correct colour. After each stepping test the mat will be rotated 90 degrees.

The spatial task requires you to listen to the words “left” and “right” spoken into either your left or right ear. If “right” is spoken into the right ear, or “left” spoken into the left ear; the answer is correct and you are required to press the “tick” button. If the word “left” is spoken into the right ear or “right” is spoken into the left ear then the answer is incorrect and you are required to press the “cross” button. Please press the button once only, do not try to correct your answer even if you know you have answered the question incorrectly.

Instructions for task 1

Stand on the central square on the mat. Look directly ahead at the computer screen. The screen will change colour at random time intervals. When the screen changes colour please place your nearest foot on the corresponding coloured square on the mat and return it to the starting position as quickly and safely as possible. The screen will change colour a number of times. Please only step once per change in colour.

Instructions for task 2

Stand on the central square on the mat. Look directly ahead at the computer screen. You are required to perform the spatial task only. This task requires you to listen to the words “left” and “right” spoken into either your left or right ear. If “right” is spoken into the right ear, or “left” spoken into the left ear; the answer is correct and you are required to press the “tick” button. If the word “left” is spoken into the right ear or “right” is spoken into the left ear then the answer is incorrect and you are required to press the “cross” button. Please press the button once only, do not try to correct your answer even if you know you have answered the question incorrectly.

Instructions for task 3

Stand on the central square on the mat. Look directly ahead at the computer screen. The screen will change colour at random time intervals. You are required to perform both the stepping task and the spatial task at the same time. When the screen changes colour please place your nearest foot on the corresponding coloured square on the mat and return it to the starting position as quickly and safely as possible. Please listen to the words “left” and “right” spoken into either your left or right ear. If “right” is spoken into the right ear, or “left” spoken into the left ear; the answer is correct and you are required to press the “tick” button. If the word “left” is spoken into the right ear or “right” is spoken into the left ear then the answer is incorrect and you are required to press the “cross” button. Please press the button once only, do not try to correct your answer even if you know you have answered the question incorrectly.

Appendix 6. INFORMATION SHEET FOR PARTICIPANTS

A comparison of balance, dizziness, and falls risk in older-adult fallers and age-matched patients with a peripheral vestibular disorder: A pilot study.

You are being invited to take part in a research project. This study is being carried out as part of a larger PhD study by Matthew Liston of King's College London. Here is some information to help you decide whether or not to take part. Before you decide whether you want to take part, it is important for you to understand why the research is being done and what your participation will involve. Please take time to read the following information carefully and discuss with friends, relatives and your GP if you wish. Please do not hesitate to ask us if there is anything you do not understand or if you would like more information. Please do take time to decide whether you wish to take part. You should only participate if you want to; choosing not to take part will not disadvantage you in any way.

Background

It has been shown that older adults who experience falls (2 or more in the previous 12 months) are more reliant on vision for balance, can have difficulty maintaining their balance when moving their head while walking and may also experience unpleasant feelings of motion or blurred vision when walking or turning their head. These are similar to symptoms experienced by individuals with balance disorders arising from the inner-ear. The balance organs of the inner ear provide the brain with information regarding head movements and work together with your eyes to help stabilise vision when you move your head. Disorders of the inner ear balance system can lead to dizziness, feelings of imbalance and blurred vision.

Many studies have tried to find out why some older people fall more than others and use this information to provide specific exercises to help decrease the number of falls a person has. Some exercise programmes have been more successful than others and further work is needed. In patients with inner ear balance disorders, exercises that work on reducing feelings of motion, blurred vision and unsteadiness while standing or walking and moving the head at the same time, have shown

significant improvements. However these types of exercise have not been used in exercise programmes for older adults who fall.

What is the purpose of this study?

As both patients with inner ear balance disorders and older adult fallers describe similar symptoms, this pilot study is designed to investigate whether there are similarities between the two groups on questionnaires and balance tests routinely assessed in patients with inner ear problems. This information will then be used to design an appropriate advanced falls rehabilitation programme for older adult fallers.

Why have I been chosen?

You have been asked to participate in this study because you have been referred to a falls clinic and you have experienced more than 2 falls in the past 12 months.

Do I have to take part?

It is up to you to decide whether to take part. We will describe the study to you and then go through this information sheet. If you agree to participate we will ask you to give your verbal consent and sign a consent form to show that you have agreed to take part. You are free to withdraw at any time without giving a reason. This will not affect the standard of care you receive.

What will happen to me if I take part?

If you decide to participate, you will be asked to attend the National Hospital for Neurology and Neurosurgery for a single visit to complete an assessment of your inner ear balance system, a brief set of questionnaires and some simple physical tests to assess your balance. The brief set of questionnaires will ask about particular symptoms and their severity (i.e. feelings of unsteadiness), the situations that may produce these symptoms (e.g. crowds), emotional state (which we know affects balance symptoms), the ability to perform various daily activities, and confidence in your ability to maintain balance in everyday activities.

Two of the physical balance tests will look at your ability to maintain your balance in standing or while walking during different conditions, such as when the surface is unsteady or when you move your head at the same time. The third test will ask you to do five tasks, which have been shown to be important in predicting falls risk. These tasks include testing muscle strength in your legs and the ability to detect objects in a cluttered environment.

You will also be asked to complete some tests to assess the function of your inner ear balance system. There is a possibility that you will feel dizzy or slightly sick (similar to motion sickness) with one of the balance tests, but this will be short lived and there are no long lasting effects. You are free to stop the tests at any time during the testing period.

It is expected that the whole testing process will take approximately 3.5 hours including regular breaks.

Are there any risks to me from taking part?

You may, on occasions feel unsteady or dizzy while performing some of the more challenging walking tasks and when undertaking the balance tests. You will be closely supervised throughout when performing all tests and will be in a safety harness for the standing balance tests. You will be able to use your walking aid during the walking tests, if this is normal for you. If you feel particularly unsteady or dizzy at any point you can stop the test at any time.

What are the benefits of taking part?

We cannot promise we will be able to help you, but, the extended assessment may help provide further information about why some older adults experience falls. The information from this study will be used to develop an advanced falls rehabilitation programme

You will also receive a comprehensive hearing and inner ear balance assessment. If any abnormalities are discovered, these will be discussed with you and a letter will be sent to your GP. If we find that you would benefit from additional balance physiotherapy, the research team would be pleased to offer you this option.

Will my taking part be kept confidential?

All information that is collected about you during the course of this research will be kept strictly confidential. All information for this project will be stored on password protected computers used only by research staff. Any documents leaving the hospital site will have all personal identifiable information removed.

Will this affect my current treatment?

Participating in this study will not affect your current treatment.

What happens if there is a problem?

This study has been reviewed by the National Hospital for Neurology and Neurosurgery and Institute of Neurology Joint Ethics Committee. The consultant in charge of this investigation is Professor Linda Luxon, Professor in Audiovestibular Medicine and Consultant Neuro-otological Physician at NHNN. Other investigators conducting this trial are Dr Doris Eva Bamiou (Consultant in Audiological Medicine, NHNN), Dr Finbarr Martin (Consultant Geriatrician, Guy's and St Thomas' Hospital), Dr. Marousa Pavlou (Lecturer in Physiotherapy, King's College London) and Mr. Matthew Liston (Physiotherapist, PhD student at King's College London).

If you have any concerns regarding the study please contact Mr. Matthew Liston, the physiotherapist who will be conducting the balance testing and who will try to answer your questions (mobile: 07838 150049). If you are unhappy and wish to complain formally, you can do this through the NHS complaints procedure. Details can be obtained from the hospital.

In the event that something does go wrong and you are harmed during the research and this is due to some-one's negligence, then you may have grounds for legal action for compensation against University College London Hospitals NHS Trust, but you may have to pay for legal costs. The normal NHS complaints procedure will still be available to you.

It is up to you to decide whether to take part or not. If you decide to take part you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect the treatment you receive from your medical or therapy team in any way. You may withdraw your data from the project at any time up until it is transcribed for use in the final report.

If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. Your data will be kept anonymously and will not be passed on outside of your medical care team.

What happens now?

You are required to read this document and if possible discuss it with relatives, friends or other healthcare workers. We will contact you by telephone within seven days to ask whether you would like to participate in the study.

Who can I contact for further information?

If you have any queries please contact Mr Matthew Liston; the Physiotherapist working on this study.

Matthew Liston
Division of Applied Biomedical Research
Room 3.11 Shepherd's House
Guy's Campus
King's College London
London Bridge
SE1 1UL
Tel: 07838 150049
Email: matthew.liston@kcl.ac.uk

Appendix 7. Consent Form

University College London Hospitals



NHS Trust

Centre Number:

09/0083

Patient Identification Number for this study:

UCLH Project ID number:

Form version:

CONSENT FORM

Title of project: A comparison of balance, dizziness and falls risk in older adult fallers and age-matched patients with a peripheral vestibular disorder: A pilot study.

Name of Principal investigator: Prof. Linda Luxon. Professor of Audio-vestibular Medicine.

Please initial box

1. I confirm that I have read and understood the information sheet dated
(version) for the above study and have had the opportunity to ask questions.

☐

2. I confirm that I have had sufficient time to consider whether or not want to be included in the study

☐

3. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected.

☐

4. I understand that sections of any of my medical notes may be looked at by responsible individuals from King's College London, The National Hospital for Neurology and Neurosurgery, Guys and St Thomas' NHS Foundation Trust or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to my records.

☐

5. I understand that relevant sections of my medical notes and data collected during the study may be looked at by individuals from King's College London, from regulatory authorities or from the NHS Trust, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my records.

☐

6. I agree to take part in the above study.

☐

Centre Number:
number:

UCLH Project ID

Patient Identification Number for this study:

Form version:

CONSENT FORM

Title of project: A comparison of balance, dizziness and falls risk in older adult fallers and age-matched patients with a peripheral vestibular disorder.

Name of Principal investigator: Prof. Linda Luxon. Professor of Audiovestibular Medicine.

Name of patient Date Signature

Name of Person taking consent Date Signature
(if different from researcher)

Researcher (to be contacted Date Signature
if there are any problems)

Comments or concerns during the study

If you have any comments or concerns you may discuss these with the investigator (Matthew Liston).

He can be contacted at: Room 3.11 Shepherds House, Division of Applied Biomedical Research, King's College London. London SE1 1UL. Tel: 07838 150049. Email: matthew.liston@kcl.ac.uk

If you wish to go further and complain about any aspect of the way you have been approached or treated during the course of the study, you should write or get in touch with the Complaints Manager, UCL hospitals. Please quote the UCLH project number at the top this consent form.

Appendix 8. INFORMATION SHEET FOR PARTICIPANTS

The effect of multisensory balance training on falls risk in older adult fallers.

You are being invited to take part in a research project. This study is being carried out as part of a larger PhD study by Matthew Liston of King's College London. Here is some information to help you decide whether or not to take part. Before you decide whether you want to take part, it is important for you to understand why the research is being done and what your participation will involve. Please take time to read the following information carefully and discuss with friends, relatives and your GP if you wish. Please do not hesitate to ask us if there is anything you do not understand or if you would like more information. Please do take time to decide whether you wish to take part. You should only participate if you want to; choosing not to take part will not disadvantage you in any way.

Background

It has been shown that older adults who experience multiple falls (2 or more in the previous 12 months) are more reliant on vision for balance, can have difficulty maintaining their balance when moving their head while walking and may also experience unpleasant feelings of motion or blurred vision when walking or turning their head. These are similar to symptoms experienced by individuals with balance disorders arising from the inner-ear.

Many studies have been performed to help develop exercise programmes to help decrease the number of falls a person has. At present the majority of falls rehabilitation programmes provide basic balance exercises and strengthening programmes to help reduce falls rates. In patients with inner ear balance disorders, exercises that work on reducing feelings of motion, blurred vision and unsteadiness while standing or walking and moving the head at the same time, provide significant improvements in balance function. Recent studies have shown that integrating some of these exercises into a balance rehabilitation programme can have a beneficial effect in older adult fallers and older adults with arthritis.

What is the purpose of this study?

The purpose of this study is to determine the effect of visual motion desensitisation and / or supplementary exercises designed to improve function of the inner ear balance system in combination with a normal falls rehabilitation programme in older adult fallers.

Why have I been chosen?

You have been asked to participate in this study because you have experienced 2 or more falls in the past 12 months and you have been referred into a falls rehabilitation programme. You have been referred by your therapist or consultant physician.

Do I have to take part?

It is up to you to decide whether to take part. We will describe the study to you and then go through this information sheet. If you agree to participate we will ask you to give your verbal consent and sign a consent form to show that you have agreed to take part. You are free to withdraw at any time without giving a reason. This will not affect the standard of care you receive.

What will happen to me if I take part?

If you decide to participate, and you have not been referred for the OTAGO exercise programme, or have been referred for the once weekly community OTAGO, you will be invited to attend supplementary OTAGO sessions at the research laboratory, King's College London, which will begin shortly after your first testing session. You will then be invited to attend the research laboratory at King's College London for a testing session to assess your balance. On this day you will have the study described to you and will be given this information sheet to read again. You will then be asked to sign a consent form if you decide to participate. After this you will be asked to fill out some questionnaires regarding your balance and how you are feeling at present and you will also be asked to perform a simple falls assessment, walking test and four short vision tests. This should take approximately one and a half hours (You will be asked to come in for the same tests on three other occasions over the following year, at 4 weeks, 8 weeks and 6 months). All of your travel expenses getting to and from the research sites will be reimbursed by the research team.

After your first testing session you will be randomly assigned into one of three groups which will determine what extra exercises you will receive. You will then

receive a supplementary physiotherapy assessment to help design your additional programme. One group will be provided with a stretching and flexibility programme and one group will have multi-sensory balance exercises. All exercises within the supplementary programme will be individually tailored to your needs. You will be asked to perform these exercises daily for the duration of the study and the whole programme should take approximately 15 – 20 minutes per day to perform. The research physiotherapist will come to visit you at home at a time convenient to you twice weekly for the first 8 weeks to assess how the exercises are being performed and to progress the exercises as required.

Are there any risks to me from taking part?

You may, on occasions feel slightly unsteady or may experience some symptoms of nausea, mild dizziness and / or disorientation (similar to motion sickness) depending upon your treatment group and your sensitivity to the exercises used. These symptoms should be short lasting and should return to normal within minutes after finishing the treatment.

Some of the balance tests may make you feel slightly unsteady, a Physiotherapist will be supervising you very closely at all times and will provide assistance if necessary. These tests are all commonly used in clinical practice.

What are the benefits of taking part?

You will be provided with a comprehensive falls rehabilitation programme designed to improve balance function and your confidence in your balance. We cannot promise to improve your balance but it is expected that the additional programmes may have a beneficial effect on your balance. The aim of this study is to test whether the additional exercises are beneficial, so that we may be able to develop better falls rehabilitation programmes in the future.

Will my taking part be kept confidential?

All information that is collected about you during the course of this research will be kept strictly confidential. All information for this project will be stored on password protected computers used only by research staff. Any documents leaving the hospital site will have all personal identifiable information removed.

Will my GP or Medical team know about my participation and results of this investigation?

With your permission we would like to inform your GP of your participation in this study.

Will this affect my current treatment?

Participating in this study will not affect your current treatment.

What happens if there is a problem?

This study has been reviewed by the Central London Research Ethics Committee. The researcher in charge of this investigation is Dr. Marousa Pavlou (Lecturer in Physiotherapy, King's College London). Other investigators conducting this trial are Professor Linda Luxon, Professor in Audiovestibular Medicine and Consultant Neuro-otological Physician at NHNN, Dr Doris Eva Bamiou (Consultant in Audiological Medicine, NHNN), Dr Finbarr Martin (Consultant Geriatrician, Guy's and St Thomas' Hospital), Dr Mark Kinirons (Consultant Geriatrician, Guy's and St Thomas' Hospital), Dr Adrian Hopper (Consultant Geriatrician, Guy's and St Thomas' Hospital) and Mr. Matthew Liston (Physiotherapist, PhD student at King's College London).

If you have any concerns regarding the study please contact Mr. Matthew Liston, the physiotherapist who will be conducting the inner ear balance system exercises who will try to answer your questions (mobile: 07838 150049). If you are unhappy and wish to complain formally, you can do this through the NHS complaints procedure. Details can be obtained from the hospital.

In the event that something does go wrong and you are harmed during the research and this is due to some-one's negligence, then you may have grounds for legal action for compensation against King's College London and / or Guy's and St Thomas' NHS Foundation Trust, but you may have to pay for legal costs. The normal NHS complaints procedure will still be available to you.

It is up to you to decide whether to take part or not. If you decide to take part you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect the treatment you receive from your medical or therapy team in any way. You may withdraw your data from the project at any time up until it is transcribed for use in the final report which is the 1st June 2011.

If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. Your data will be kept anonymously and will not be passed on outside of your medical care team.

Who can I contact for further information?

If you have any queries please contact Mr Matthew Liston; the Physiotherapist working on this study.

Matthew Liston

Centre of Human and Aerospace Physiological Sciences

Room 3.11 Shepherd's House

Guy's Campus

King's College London

London Bridge

SE1 1UL

Tel: 07838 150049

Email:

matthew.liston@kcl.ac.uk

Appendix 9. The OTAGO Exercise Programme

TABLE 4 LEVELS AND NUMBER OF REPETITIONS FOR THE STRENGTHENING AND BALANCE RETRAINING EXERCISES

Strengthening exercises					
1	Knee extensor (front knee strength)	ALL 4 LEVELS Ankle cuff weights are used to provide resistance to the muscles and 10 repetitions of each exercise are carried out			
2	Knee flexor (back knee strength)				
3	Hip abductor (side hip strength)				
4	Ankle plantarflexors (calf raises)	LEVEL C 10 repetitions, hold support, repeat	LEVEL D 10 repetitions, no support, repeat		
5	Ankle dorsiflexors (toe raises)	10 repetitions, hold support, repeat	10 repetitions, no support, repeat		
Balance retraining exercises					
		LEVEL A	LEVEL B	LEVEL C	LEVEL D
1	Knee bends	10 repetitions Hold support	i) 10 repetitions, no support or ii) 10 repetitions, hold support, repeat	10 repetitions No support, repeat	3 x 10 repetitions No support
2	Backwards walking		10 steps, 4 times Hold support		10 steps, 4 times No support
3	Walking and turning around		Walk and turn around (make figure of 8) twice Use walking aid	Walk and turn around (make figure of 8) twice No support	
4	Sideways walking		10 steps, 4 times Use walking aid	10 steps, 4 times No support	
5	Tandem stance (heel toe stand)	10 seconds Hold support	10 seconds No support		
6	Tandem walk (heel toe walk)			Walk 10 steps Hold support, repeat	Walk 10 steps No support, repeat
7	One leg stand		10 seconds, hold support	10 seconds, no hold	30 seconds, no hold
8	Heel walking			10 steps, 4 times Hold support	10 steps, 4 times No support
9	Toe walk			10 steps, 4 times Hold support	10 steps, 4 times No support
10	Heel toe walking backwards				Walk 10 steps No support, repeat
11	Sit to stand	5 stands, 2 hands for support	i) 5 stands, one hand or ii) 10 stands, 2 hands for support	i) 10 stands, no support or ii) 10 stands, 1 hand for support, repeat	10 stands, no support Repeat

APPENDIX 2 1 EXERCISE PRESCRIPTION CHART

Name	Visit 1	Visit 2	Visit 3
Date			
1 Head movements			
2 Neck movements			
3 Back extension			
4 Trunk movements			
5 Ankle movements			
	* LEVEL	LEVEL	LEVEL
1 Front knee strengthen (kg)			
2 Back knee strengthen (kg)			
3 Side hip strengthen (kg)			
4 Calf raises			
5 Toe raises			
1 Knee bends			
2 Backwards walk			
3 Walk and turn			
4 Sideways walk			
5 Heel toe stand			
6 Heel toe walk			
7 One leg stand			
8 Heel walking			
9 Toe walking			
10 Heel toe walk backwards			
11 Sit to stand			
12 Stair walking (number)			
Walking time (minutes)			

* see Table 4, page 19 for level of difficulty A to D; if an exercise is not prescribed put a dash (—)

Appendix 10. Outcome Measures

Functional Gait Assessment (FGA)

Requirements: A marked 6-m (20-ft) walkway that is marked with a 30.48-cm (12-in) width.

1. GAIT LEVEL SURFACE

Instructions: *Walk at your normal speed from here to the next mark (6 m [20 ft]).*

Grading: Mark the highest category that applies.

(3) Normal—Walks 6 m (20 ft) in less than 5.5 seconds, no assistive devices, good speed, no evidence for imbalance, normal gait pattern, deviates no more than 15.24 cm (6 in) outside of the 30.48-cm (12-in) walkway width.

(2) Mild impairment—Walks 6 m (20 ft) in less than 7 seconds but greater than 5.5 seconds, uses assistive device, slower speed, mild gait deviations, or deviates 15.24–25.4 cm (6–10 in) outside of the 30.48-cm (12-in) walkway width.

(1) Moderate impairment—Walks 6 m (20 ft), slow speed, abnormal gait pattern, evidence for imbalance, or deviates 25.4–38.1 cm (10–15 in) outside of the 30.48-cm (12-in) walkway width. Requires more than 7 seconds to ambulate 6 m (20 ft).

(0) Severe impairment—Cannot walk 6 m (20 ft) without assistance, severe gait deviations or imbalance, deviates greater than 38.1 cm (15 in) outside of the 30.48-cm (12-in) walkway width or reaches and touches the wall.

2. CHANGE IN GAIT SPEED

Instructions: *Begin walking at your normal pace (for 1.5 m [5 ft]). When I tell you “go,” walk as fast as you can (for 1.5 m [5 ft]). When I tell you “slow,” walk as slowly as you can (for 1.5 m [5 ft]).*

Grading: Mark the highest category that applies.

(3) Normal—Able to smoothly change walking speed without loss of balance or gait deviation. Shows a significant difference in walking speeds between normal, fast, and slow speeds. Deviates no more than 15.24 cm (6 in) outside of the 30.48-cm (12-in) walkway width.

(2) Mild impairment—Is able to change speed but demonstrates mild gait deviations, deviates 15.24–25.4 cm (6–10 in) outside of the 30.48-cm (12-in) walkway width, or no gait deviations but unable to achieve a significant change in velocity, or uses an assistive device.

(1) Moderate impairment—Makes only minor adjustments to walking speed, or accomplishes a change in speed with significant gait deviations, deviates 25.4–38.1 cm (10–15 in) outside the 30.48-cm (12-in) walkway width, or changes speed but loses balance but is able to recover and continue walking.

(0) Severe impairment—Cannot change speeds, deviates greater than 38.1 cm (15 in) outside 30.48-cm (12-in) walkway width, or loses balance and has to reach for wall or be caught.

3. GAIT WITH HORIZONTAL HEAD TURNS

Instructions: *Walk from here to the next mark 6 m (20 ft) away. Begin walking at your normal pace. Keep walking straight; after 3 steps, turn your head to the right and keep walking straight while looking to the right. After 3 more steps, turn your head to the left and keep walking straight while looking left. Continue alternating looking right and left every 3 steps until you have completed 2 repetitions in each direction.*

Grading: Mark the highest category that applies.

(3) Normal—Performs head turns smoothly with no change in gait. Deviates no more than 15.24 cm (6 in) outside 30.48-cm (12-in) walkway width.

(2) Mild impairment—Performs head turns smoothly with slight change in gait velocity (eg, minor disruption to smooth gait path), deviates 15.24–25.4 cm (6–10 in) outside 30.48-cm (12-in) walkway width, or uses an assistive device.

(1) Moderate impairment—Performs head turns with moderate change in gait velocity, slows down, deviates 25.4–38.1 cm (10–15 in) outside 30.48-cm (12-in) walkway width but recovers, can continue to walk.

(0) Severe impairment—Performs task with severe disruption of gait (eg, staggers 38.1 cm [15 in] outside 30.48-cm (12-in) walkway width, loses balance, stops, or reaches for wall).

4. GAIT WITH VERTICAL HEAD TURNS

Instructions: *Walk from here to the next mark (6 m [20 ft]). Begin walking at your normal pace. Keep walking straight; after 3 steps, tip your head up and keep walking straight while looking up. After 3 more steps, tip your head down, keep walking straight while looking down. Continue alternating looking up and down every 3 steps until you have completed 2 repetitions in each direction.*

Grading: Mark the highest category that applies.

(3) Normal—Performs head turns with no change in gait. Deviates no more than 15.24 cm (6 in) outside 30.48-cm (12-in) walkway width.

(2) Mild impairment—Performs task with slight change in gait velocity (eg, minor disruption to smooth gait path), deviates 15.24–25.4 cm (6–10 in) outside 30.48-cm (12-in) walkway width or uses assistive device.

(1) Moderate impairment—Performs task with moderate change in gait velocity, slows down, deviates 25.4–38.1 cm (10–15 in) outside 30.48-cm (12-in) walkway width but recovers, can continue to walk.

(0) Severe impairment—Performs task with severe disruption of gait (eg, staggers 38.1 cm [15 in] outside 30.48-cm (12-in) walkway width, loses balance, stops, reaches for wall).

5. GAIT AND PIVOT TURN

Instructions: *Begin with walking at your normal pace. When I tell you, "turn and stop," turn as quickly as you can to face the opposite direction and stop.*

Grading: Mark the highest category that applies.

(3) Normal—Pivot turns safely within 3 seconds and stops quickly with no loss of balance.

(2) Mild impairment—Pivot turns safely in 3 seconds and stops with no loss of balance, or pivot turns safely within 3 seconds and stops with mild imbalance, requires small steps to catch balance.

(1) Moderate impairment—Turns slowly, requires verbal cueing, or requires several small steps to catch balance following turn and stop.

(0) Severe impairment—Cannot turn safely, requires assistance to turn and stop.

6. STEP OVER OBSTACLE

Instructions: *Begin walking at your normal speed. When you come to the shoe box, step over it, not around it, and keep walking.*

Grading: Mark the highest category that applies.

(3) Normal—Is able to step over 2 stacked shoe boxes taped together (22.86 cm [9 in] total height) without changing gait speed; no evidence of imbalance.

(2) Mild impairment—Is able to step over one shoe box (11.43 cm [4.5 in] total height) without changing gait speed; no evidence of imbalance.

(1) Moderate impairment—Is able to step over one shoe box (11.43 cm [4.5 in] total height) but must slow down and adjust steps to clear box safely. May require verbal cueing.

(0) Severe impairment—Cannot perform without assistance.

7. GAIT WITH NARROW BASE OF SUPPORT

Instructions: *Walk on the floor with arms folded across the chest, feet aligned heel to toe in tandem for a distance of 3.6 m [12 ft]. The number of steps taken in a straight line are counted for a maximum of 10 steps.*

Grading: Mark the highest category that applies.

(3) Normal—Is able to ambulate for 10 steps heel to toe with no staggering.

(2) Mild impairment—Ambulates 7–9 steps.

(1) Moderate impairment—Ambulates 4–7 steps.

(0) Severe impairment—Ambulates less than 4 steps heel to toe or cannot perform without assistance.

8. GAIT WITH EYES CLOSED

Instructions: *Walk at your normal speed from here to the next mark (6 m [20 ft]) with your eyes closed.*

Grading: Mark the highest category that applies.

(3) Normal—Walks 6 m (20 ft), no assistive devices, good speed, no evidence of imbalance, normal gait pattern, deviates no more than 15.24 cm (6 in) outside 30.48-cm (12-in) walkway width. Ambulates 6 m (20 ft) in less than 7 seconds.

(2) Mild impairment—Walks 6 m (20 ft), uses assistive device, slower speed, mild gait deviations, deviates 15.24–25.4 cm (6–10 in) outside 30.48-cm (12-in) walkway width. Ambulates 6 m (20 ft) in less than 9 seconds but greater than 7 seconds.

(1) Moderate impairment—Walks 6 m (20 ft), slow speed, abnormal gait pattern, evidence for imbalance, deviates 25.4–38.1 cm (10–15 in) outside 30.48-cm (12-in) walkway width. Requires more than 9 seconds to ambulate 6 m (20 ft).

(0) Severe impairment—Cannot walk 6 m (20 ft) without assistance, severe gait deviations or imbalance, deviates greater than 38.1 cm (15 in) outside 30.48-cm (12-in) walkway width or will not attempt task.

9. AMBULATING BACKWARDS

Instructions: *Walk backwards until I tell you to stop.*

Grading: Mark the highest category that applies.

(3) Normal—Walks 6 m (20 ft), no assistive devices, good speed, no evidence for imbalance, normal gait pattern, deviates no more than 15.24 cm (6 in) outside 30.48-cm (12-in) walkway width.

(2) Mild impairment—Walks 6 m (20 ft), uses assistive device, slower speed, mild gait deviations, deviates 15.24–25.4 cm (6–10 in) outside 30.48-cm (12-in) walkway width.

(1) Moderate impairment—Walks 6 m (20 ft), slow speed, abnormal gait pattern, evidence for imbalance, deviates 25.4–38.1 cm (10–15 in) outside 30.48-cm (12-in) walkway width.

(0) Severe impairment—Cannot walk 6 m (20 ft) without assistance, severe gait deviations or imbalance, deviates greater than 38.1 cm (15 in) outside 30.48-cm (12-in) walkway width or will not attempt task.

10. STEPS

Instructions: *Walk up these stairs as you would at home (ie, using the rail if necessary). At the top turn around and walk down.*

Grading: Mark the highest category that applies.

(3) Normal—Alternating feet, no rail.

(2) Mild impairment—Alternating feet, must use rail.

(1) Moderate impairment—Two feet to a stair; must use rail.

(0) Severe impairment—Cannot do safely.

Hospital Anxiety and Depression Scale (HADS)

Emotions play an important part in most medical conditions. The following questions are designed to help us know about how you feel and how things have been since the onset of your condition. Read each item and **TICK** the reply which comes closest to how you have been feeling since your symptoms began. Don't take too long over your replies; your immediate reaction to each item will probably be more accurate than a long thought out response.

1) I feel tense or 'wound up':		8) I feel as if I am slowed down:		
Most of the time		Nearly all of the time		
A lot of the time		Very often		
Time to time, occasionally		Sometimes		
Not at all		Not at all		
2) I still enjoy the things I used to enjoy:		9) I get a sort of frightened feeling like 'butterflies in the stomach':		
Definitely as much		Not at all		
Not quite so much		Occasionally		
Only a little		Quite often		
Not at all		Very often		
3) I get a sort of frightened feeling like something awful is about to happen:		10) I have lost interest in my appearance:		
Very definitely and quite badly		Definitely		
Yes, but not too badly		I don't take as much care as I should		
A little, but it doesn't worry me		I may not take quite as much care		
Not at all		I take just as much care as ever		

4) I can laugh and see the funny side of things:		11) I feel restless as if I have to be on the move:		
As much as I always could		Very much indeed		
Not quite so much now		Quite a lot		
Definitely not so much now		Not very much		
Not at all		Not at all		
5) Worrying thoughts go through my mind:		12) I look forward with enjoyment to things:		
A great deal of the time		A much as I ever did		
A lot of the time		Rather less than I used to		
From time to time but not too often		Definitely less than I used to		
Only occasionally		Hardly at all		
6) I feel cheerful:		13) I get sudden feelings of panic:		
Not at all		Very often indeed		
Not often		Quite often		
Sometimes		Not very often		
Most of the time		Not at all		
7) I can sit at ease and feel relaxed:		14) I can enjoy a good book or radio or TV programme:		
Definitely		Often		
Usually		Sometimes		
Not often		Not often		
Not at all		Very seldom		

The Activities-Specific Balance Confidence (ABC) Scale*

Instructions to Participants:

For each of the following, please indicate your level of confidence in doing the activity without losing your balance or becoming unsteady from choosing one of the percentage points on the scale from 0% to 100%. If you do not currently do the activity in question, try and imagine how confident you would be if you had to do the activity. If you normally use a walking aid to do the activity or hold onto someone, rate your confidence as if you were using these supports. If you have any questions about answering any of these items, please ask the administrator.

For each of the following activities, please indicate your level of self confidence by choosing a corresponding number from the following rating scale:

0% 10 20 30 40 50 60 70 80 90 100%
no confidence completely confident

“How confident are you that you will not lose your balance or become unsteady when you...

1. ...walk around the house? ____%
2. ...walk up or down stairs? ____%
3. ...bend over and pick up a slipper from the front of a closet floor ____%
4. ...reach for a small can off a shelf at eye level? ____%
5. ...stand on your tiptoes and reach for something above your head? ____%
6. ...stand on a chair and reach for something? ____%
7. ...sweep the floor? ____%
8. ...walk outside the house to a car parked in the driveway? ____%
9. ...get into or out of a car? ____%
10. ...walk across a parking lot to the mall? ____%
11. ...walk up or down a ramp? ____%
12. ...walk in a crowded mall where people rapidly walk past you? ____%
13. ...are bumped into by people as you walk through the mall? ____%
14. ... step onto or off an escalator while you are holding onto a railing? ____%
15. ... step onto or off an escalator while holding onto parcels such that you cannot hold onto the railing? ____%
16. ...walk outside on icy sidewalks? ____%

*Powell, LE & Myers AM. The Activities-specific Balance Confidence (ABC) Scale. *J Gerontol Med Sci* 1995; 50(1): M28-34

SITUATIONAL CHARACTERISITIC QUESTIONNAIRE

Vertigo is the medical term used for symptoms which patients often describe as feelings of unusual disorientation, dizziness, giddiness, lightheadedness or unsteadiness. Please ring a number to indicate the degree to which each of the situations listed below causes feelings of vertigo, or makes your vertigo worse. If you have never been in one of the situations then for that item ring "N.T." for "Not Tried".

The categories are:

	0	1	2	3	4	N.T.
	Not at all	Very slightly	Somewhat	Quite a lot	Very much	Not tried
1) Riding as a passenger in a car on straight, flat roads	0	1	2	3	4	N.T.
2) Riding as a passenger in a car on winding or bumpy roads	0	1	2	3	4	N.T.
3) Walking down a supermarket aisle	0	1	2	3	4	N.T.
4) Standing in a lift while it stops	0	1	2	3	4	N.T.
5) Standing in a lift while it moves at a steady speed	0	1	2	3	4	N.T.
6) Riding in a car at a steady speed N.T.	0	1	2	3	4	
7) Starting or stopping in a car	0	1	2	3	4	N.T.
8) Standing in the middle of a wide open space	0	1	2	3	4	N.T.
9) Sitting on a bus	0	1	2	3	4	N.T.
10) Standing on a bus	0	1	2	3	4	N.T.
11) Heights	0	1	2	3	4	N.T.
12) Watching moving scenes on the T.V. or at the cinema	0	1	2	3	4	N.T.
13) Travelling on escalators	0	1	2	3	4	N.T.
14) Looking at striped or moving surfaces (e.g. curtains, Venetian blinds, flowing water)	0	1	2	3	4	N.T.
15) Looking at a scrolling computer screen or microfiche	0	1	2	3	4	N.T.
16) Going through a tunnel looking at the lights on the side	0	1	2	3	4	N.T.
17) Going through a tunnel looking at the light at the end	0	1	2	3	4	N.T.
18) Driving over the brow of a hill, around bends, or in wide open spaces	0	1	2	3	4	N.T.
19) Watching moving traffic or trains (e.g. trying to cross the street, or at the station)	0	1	2	3	4	N.T.

Vertigo Symptom Scale

The following questions ask about the type of symptoms you experience and how often they occur. Please circle the appropriate number to indicate about how many times you have experienced each of the symptoms listed below during the past month

The meanings of the number responses are:

0	1	2	3	4
Never	A few times (1-3 times a month)	Several times (4-12 times a month)	Quite often (on average more than 4-7 times a week)	Very often (on average more than once a day)

How often **in the past month** have you had the following symptoms:

1. A feeling that things are spinning or moving around, lasting (PLEASE ANSWER ALL THE CATEGORIES)

a) less than 2 minutes	0	1	2	3	4
b) up to 20 minutes	0	1	2	3	4
c) 20 minutes to 1 hour	0	1	2	3	4
d) several hours	0	1	2	3	4
e) more than 12 hours	0	1	2	3	4

2. Pains in the heart or chest region	0	1	2	3	4
---------------------------------------	---	---	---	---	---

	0	1	2	3	4
3. Hot or cold spells					

4. Unsteadiness so severe that you actually fall 0 1 2 3 4

5. Nausea (feeling sick), stomach churning	0	1	2	3	4
--	---	---	---	---	---

6. Tension/soreness in your muscles	0	1	2	3	4
-------------------------------------	---	---	---	---	---

7. A feeling of being light-headed, "swimmy" or giddy, lasting: (PLEASE ANSWER ALL THE CATEGORIES)

a) less than 2 minutes	0	1	2	3	4
b) up to 20 minutes	0	1	2	3	4
c) 20 minutes to 1 hour	0	1	2	3	4
d) several hours	0	1	2	3	4
e) more than 12 hours	0	1	2	3	4

8. Trembling, shivering	0	1	2	3	4
-------------------------	---	---	---	---	---

9. Feeling of pressure in the ear(s)	0	1	2	3	4
--------------------------------------	---	---	---	---	---

10. Heart pounding or fluttering	0	1	2	3	4
----------------------------------	---	---	---	---	---

11. Vomiting	0	1	2	3	4
--------------	---	---	---	---	---

12. Heavy feeling in arms or legs	0	1	2	3	4
-----------------------------------	---	---	---	---	---

13. Visual disturbances (e.g. blurring, flickering, spots before the eyes)	0	1	2	3	4
14. Headache or feeling of pressure in the head	0	1	2	3	4
15. Unable to stand or walk properly without support	0	1	2	3	4
16. Difficulty breathing, short of breath	0	1	2	3	4
17. Loss of concentration or memory	0	1	2	3	4
18. Feeling unsteady, about to lose balance, lasting: (PLEASE ANSWER <u>ALL</u> THE CATEGORIES)					
a) less than 20 minutes	0	1	2	3	4
b) up to 20 minutes	0	1	2	3	4
c) 20 minutes to 1 hour	0	1	2	3	4
d) several hours	0	1	2	3	4
e) more than 12 hours	0	1	2	3	4
19. Tingling, prickling or numbness in parts of the body	0	1	2	3	4
20. Pains in the lower part of your back	0	1	2	3	4
21. Excessive sweating	0	1	2	3	4
22. Feeling faint, about to black out	0	1	2	3	4

Vestibular Disorders Activities of Daily Living Scale

Name/ID _____

Rater _____

Date _____

Instructions

This scale evaluates the effects of vertigo and balance disorders on independence in routine activities of daily living. Please rate your performance on each item. If your performance varies due to intermittent dizziness or balance problems please use the greatest level of disability. For each task indicate the level which most accurately describes how you perform the task. If you never do a particular task, please check the box in column **NA**. The rating scales are explained on bottom of page.

Independence Rating

Task	1 <i>Independent</i>	2 <i>Uncomfortable. No Change in Ability</i>	3 <i>Decreased Ability. No Change in Manner of Performance</i>	4 <i>Slower, Cautious. More Careful</i>	5 <i>Prefer Using an Object for Help</i>	6 <i>Must Use an Object for Help</i>	7 <i>Must Use Special Equipment</i>	8 <i>Need Physical Assistance</i>	9 <i>Dependent</i>	10 <i>Too Difficult. No Longer Perform</i>	NA
F-1 Sitting up from lying down											
F-2 Standing up from sitting on the bed or chair											
F-3 Dressing the upper body (eg. shirt, brassiere, undershirt)											
F-4 Dressing the lower body (eg. pants, skirt, underpants)											
F-5 Putting on socks or stockings											
F-6 Putting on shoes											
F-7 Moving in or out of the bathtub or shower											
F-8 Bathing yourself in the bathtub or shower											
F-9 Reaching overhead (eg. to a cupboard or shelf)											
F-10 Reaching down (eg. to the floor or a shelf)											
F-11 Meal preparation											
F-12 Intimate activity (eg. foreplay, sexual activity)											
A-13 Walking on level surfaces											
A-14 Walking on uneven surfaces											
A-15 Going up steps											
A-16 Going down steps											
A-17 Walking in narrow spaces (eg. corridor, grocery store aisle)											
A-18 Walking in open spaces											
A-19 Walking in crowds											
A-20 Using an elevator											
A-21 Using an escalator											
I-22 Driving a car											
I-23 Carrying things while walking (eg. package, garbage bag)											
I-24 Light household chores (eg. dusting, putting items away)											
I-25 Heavy household chores (eg. vacuuming, moving furniture)											
I-26 Active recreation (eg. sports, gardening)											
I-27 Occupational role (eg. job, child care, homemaking, student)											
I-28 Traveling around the community (car, bus)											

Explanation of Independence Rating Scale

This scale will help us to determine how inner ear problems affect your ability to perform each task. Please indicate your current performance on each task, as compared to your performance before developing an inner ear problem, by checking one of the columns in the center of the page. Pick the answer that most accurately describes how you perform the task.

1. I am **not disabled**, perceive no change in performance from before developing an inner ear impairment.
2. I am **uncomfortable** performing the activity but **perceive no difference** in the quality of my performance.
3. I **perceive a decrement** in the quality of my performance, **but have not changed** the manner of my performance.
4. I **have changed** the manner of my performance, eg. I do things more slowly or carefully than before, or I do things without bending.
5. I **prefer using an ordinary object** in the environment for assistance (eg. stair railing) but I am not dependent on the object or device to do the activity.
6. I **must use** an ordinary object in the environment for assistance, but I have not acquired a device specifically designed for the particular activity.
7. I must use **adaptive equipment** designed for the particular activity (eg. grab bars, cane, reachers, bus with lift, wedge pillow).
8. I require another person for **physical assistance** or, for an activity involving 2 people, I need unusual physical assistance.
9. I am **dependent** on another person to perform the activity.
10. I **no longer perform** the activity due to vertigo or a balance problem.

NA. I **do not usually perform this task** or I **prefer not to answer** this question.

Appendix 11. Examples of a home exercise programmes

Home Multi-Sensory Rehabilitation Programme (Group M)

Routine For:
Created By: Matt Liston

General Safety Tips

- The purpose of these exercises is to improve the ability to maintain balance during sitting, standing, or walking activities, and to increase one's general activity level and safety in a variety of home and community situations.
- For safety, all exercises must be performed close to a support surface (wall, countertop) or next to someone.
- Only perform those exercises as instructed by the therapist. If instructions are not clearly understood, wait for clarification by therapist before attempting to perform.

SITTING - 9 Unsupported Anterior / Posterior Weight Shift: Upper Trunk Leading

Sit with feet flat on floor. Leading with head and shoulders bend down reaching forward with both arms toward ground. Return to upright position. Lean head and shoulders back looking up toward ceiling.

Hold each position 5 seconds.
Repeat 5 times per session.
Do 2 sessions per day.

 Repeat on compliant surface .



SITTING - 14 Reaching / Placing Objects in Diagonal Pattern

Pick up object located down on right and place up on left. Then pick up object located down on left and place up on right.

Repeat 10 times per session.
Do 2 sessions per day.

 Repeat on compliant surface .



STANDING STATIC - 6 Feet Together (Compliant Surface)

Stand on a cushion with feet together. Look straight ahead at stationary object. Perform with arms across chest. When able perform with eyes closed.

Hold 60 seconds.
Repeat 1 times per session.
Do 2 sessions per day.



STANDING DYNAMIC - 1 Weight Shift: Anterior / Posterior (Limits of Stability)

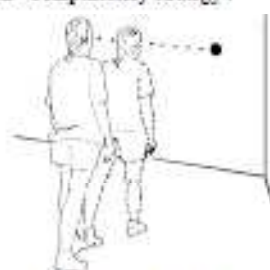
Slowly shift weight backward until toes begin to rise off floor. Return to starting position. Shift weight forward until heels begin to rise off floor.

Hold each position 5 seconds.
Repeat 10 times per session.
Do 2 sessions per day.

 Repeat on compliant surface .



GAIT - 25 Gaze Fixation - Compensatory Strategy



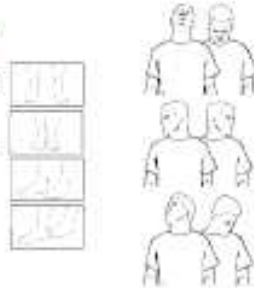
Focus on a target at eye level while walking forward and backwards across the room and simultaneously turning your head left and right always trying to keep the target in focus. Perform for one minute, twice a day.

Routine For:
 Created By: Matt Liston

STANDING STATIC - 25
 Eyes Closed: Head Motion - Varied Foot Positions

Stand with your feet together and your EYES CLOSED. Nod your head up and down as far as you can.

Perform for one minute twice daily.



Stand tall with your EYES CLOSED.

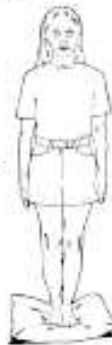
Slowly shift weight backward until toes begin to rise off floor. Return to starting position. Shift weight forward until heels begin to rise off floor.

Perform for 1 minute twice daily



STANDING STATIC - 14
 Eyes Closed: Feet Together (Compliant Surface)

Stand on a foam cushion with your EYES CLOSED and feet together. Try and remain upright and as still as possible for 1 minute. Perform twice daily



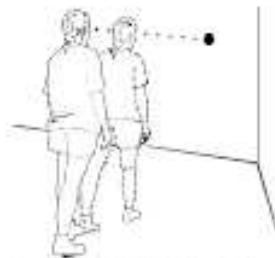
GAIT - 18
 Picking Up / Carrying Object



Whilst walking, pick up an object from the floor and carry for a couple of steps. Throw the object to the floor and repeat.

Perform for one minute, twice daily.

Repeat sequence _____ times per session. Do _____ sessions per day.



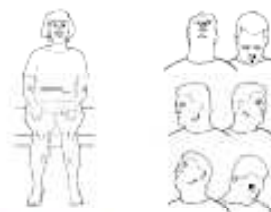
1. Focus on a target at eye level while walking forward and backwards across the room and simultaneously turning your head left and right always trying to keep the target in focus. It is best to perform this exercise alongside a wall. Do not touch the wall unless you feel unsteady. Perform for one minute, twice a day.

Example of a home Multi-Sensory Rehabilitation Programme (Group M)

General Safety Tips

- The purpose of these exercises is to improve the ability to maintain balance during sitting, standing, or walking activities, and to increase one's general activity level and safety in a variety of home and community situations.
- For safety, all exercises must be performed close to a support surface (wall, countertop) or next to someone.
- Only perform these exercises as instructed by the therapist. If instructions are not clearly understood, wait for clarification by therapist before attempting to perform.

SITTING - 18 Head Motion



With feet flat on floor, hands resting on lap, close your eyes and nod your head up and down.

Repeat for 1 minute and perform two sessions per day.

When this becomes easy, repeat while sitting on a compliant surface such as a soft cushion.

EYE EXERCISES - 7

Compensatory Strategies: Corrective Saccades

1. Hold two stationary targets placed 12 inches apart at eye level. Turn your head and eyes to the target.

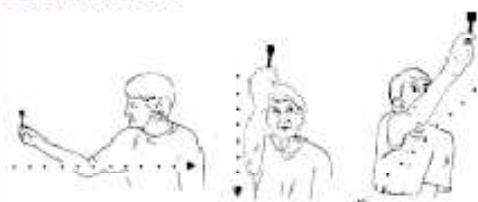
2. Then turn your head and move your eyes to the next target. Keep moving your head and eyes from target to target.

Continue for 1 minute

Perform twice daily



EYE EXERCISES - 3

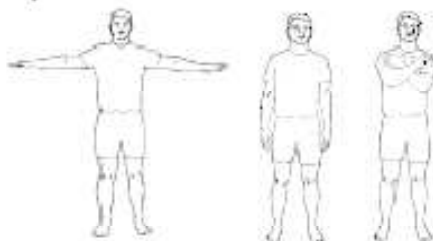


Focus on a word on a business card held in front of you at arms length. Keeping your head still and eyes fixed on the word; move the card up and down. Follow the word with your eyes.

Perform for 1 minute, twice daily.

STANDING STATIC - 1

Feet Apart: Varied Arm Positions



Standing in the corner of the room and with your eyes open. Stand with your feet shoulder width apart and arms at sides, and look straight ahead at a stationary object.

Stand for 1 minute. Twice daily.

GAIT - 1 Walking

Walk forwards and backwards in your hallway. Concentrate on picking both feet up and taking slightly longer steps.

Use the wall for support if required

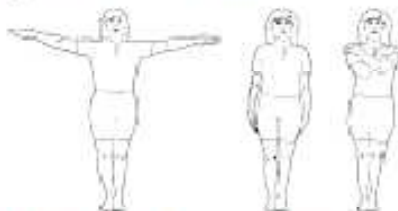
Perform for 1 minute.
Perform twice daily.



Example of a home Multi-Sensory Rehabilitation Programme (Group M)

STANDING STATIC - 2

Feet Together: Varied Arm Positions



Stand tall with your feet close together and your EYES OPEN. Look directly ahead and try to stand as tall and as steady as possible. If you feel yourself falling backwards bring your chest forwards to counteract this.

Perform for one minute, twice daily.

STANDING STATIC - 9

Eyes Closed: Feet Apart

Stand tall with your EYES CLOSED and your feet shoulders width apart. Try to stand as steady as possible.

Stand for 1 minute, twice daily



Stand with your feet shoulders width apart and your EYES OPEN. Slowly shift your weight backward until your toes begin to rise off of the floor. Return to the central starting position. Shift your weight forward until your heels begin to rise off of the floor.

This exercise is best performed with a sturdy chair in front of you for support.

Hold each position for 2 seconds.

Perform for 1 minute, twice daily



Stand with your feet shoulders width apart and your EYES OPEN. Begin to march on the spot, slowly lifting your knees toward ceiling in a controlled fashion.

You may want to perform this initially with a sturdy chair placed in front of you for support if required.

Perform for 1 minute, twice daily



Walk forwards and backwards with your eyes open whilst keeping your eyes fixed on a target placed in front of you at eye level.

Concentrate on taking long steps, picking your feet up, and bending your hips and knees. Always make sure that your heel touches the floor first when walking forwards.

Perform for 1 minute, twice daily.

Example of a Home Stretching Programme (Group C)

LOWER LEG - 4 Soleus

Keep back leg slightly bent, with heel on floor. Lean into wall until a stretch is felt in calf. Hold 30 seconds. Repeat with other leg.



Repeat 2 times.
Do 2 sessions per day.

LOWER LEG - 5 Gastroc

Keeping back leg straight, with heel on floor and turned slightly outward, lean into wall until a stretch is felt in calf. Hold 30 seconds. Repeat with other leg.



Repeat 2 times.
Do 2 sessions per day.

SHOULDERS - 2 Rotator Cuff / Extensors



Bring right hand behind head and down as far as possible. Reach up with left hand, palm facing out, and grasp right hand. Hold 30 seconds. May use belt as a beginner aid to help work hands closer together. Repeat with other side.

Do 2 sessions per day.

SHOULDERS - 3 Posterior Deltoids / Rhomboids

Pull arm across chest until stretch is felt. Turn head away from pull. Hold 30 seconds. Repeat with other arm.



Do 2 sessions per day.

SHOULDERS - 5 Deltoids

With fingers interlaced behind back, straighten arms and turn elbows in until stretch is felt. Hold 30 seconds.



Repeat 2 times.
Do 2 sessions per day.

Example of a Home Stretching Programme (Group C)

ARMS - 6 Biceps

With right arm resting comfortably on table behind, apply gentle force down and slightly forward through shoulder. Hold 30 seconds. Relax.

Repeat for the left arm.



Do 1 sessions per day.

ARMS - 5 Triceps

Pull elbow behind head until stretch is felt. Repeat with other elbow. Hold 30 seconds.



Repeat 2 times.
Do 2 sessions per day.

ARMS - 4 Wrist / Flexors

With fingers interlaced and palms out, straighten arms in front of you until stretch is felt. Hold 30 seconds.



Do 2 sessions per day.

CHEST AND ABDOMEN - 7 Pectorals

Keep palm of right hand against door frame and elbow bent at 90°. Turn body from fixed hand until stretch is felt. Hold 30 seconds. Repeat for the left side.



Repeat 1 times.
Do 1 sessions per day.

LOWER LEG 1 Ankle Plantar / Dorsiflexion



Relax leg. Gently bend and straighten ankle. Move through full range of motion. Avoid pain. Repeat with other ankle.

Repeat 20 times. Do 2 sessions per day.

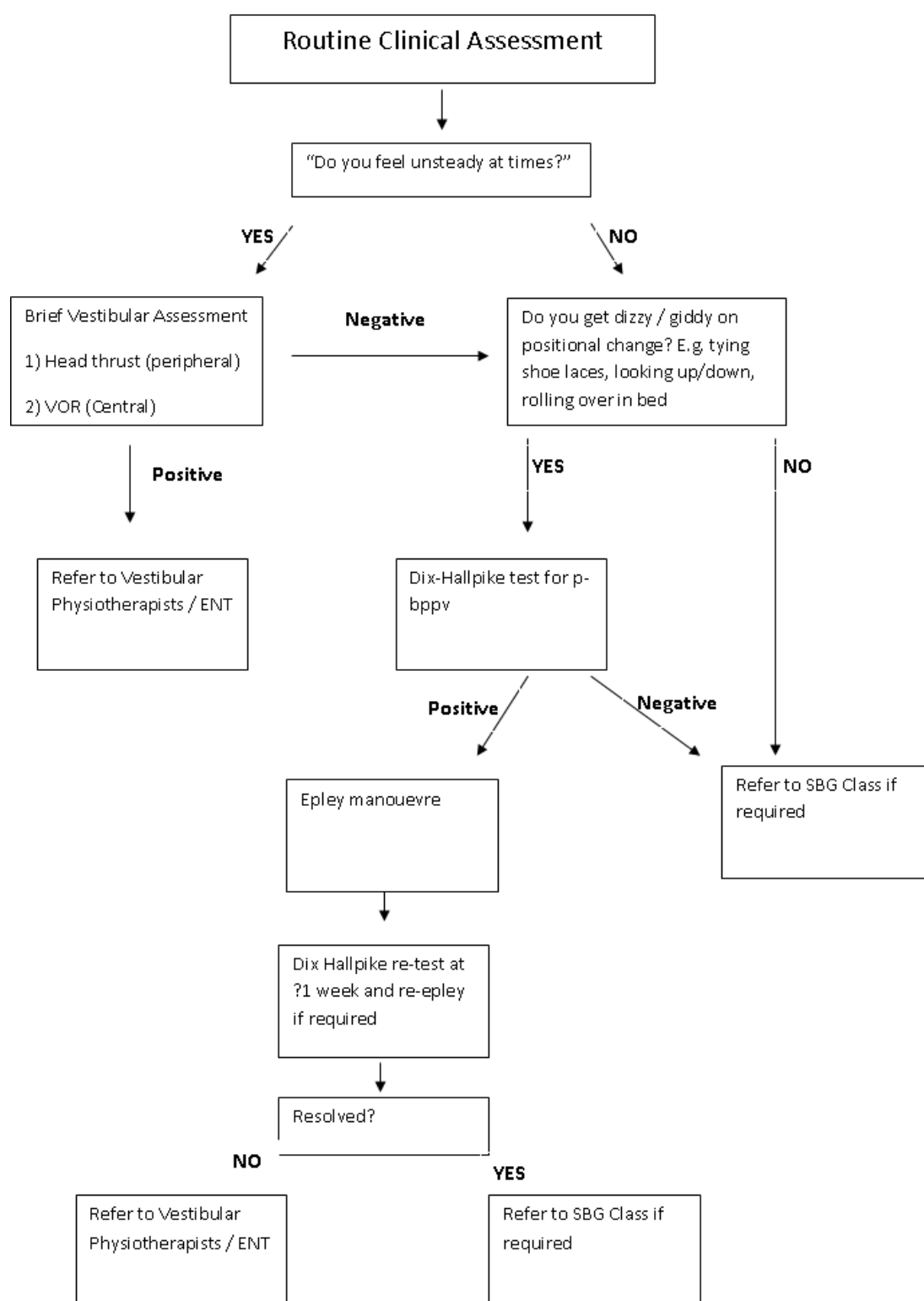
LOWER LEG 2 Ankle Inversion / Eversion

With leg relaxed, gently turn ankle and foot in and out. Move through full range of motion. Avoid pain. Repeat with other leg.



Repeat 20 times.
Do 2 sessions per day.

Appendix 12. Vestibular Pathway for Fallers



Appendix 13. The Physiological Profile Assessment: Clinical Validity of the postural sway measure and comparison of impairments by age. European Geriatric Medicine.

European Geriatric Medicine 3 (2012) 5–8



Available online at
SciVerse ScienceDirect
www.sciencedirect.com

Elsevier Masson France
EM|consulte
www.em-consulte.com/en



Research paper

The Physiological Profile Assessment: Clinical validity of the postural sway measure and comparison of impairments by age

M.B. Liston ^{a,*}, M. Paylou ^a, A. Hopper ^b, M. Kinirons ^b, F.C. Martin ^b

^a Centre of Human and Aerospace Physiological Sciences, School of Biomedical Sciences, King's College London, London, UK

^b Department of Safety Care Medicine, Guy's and St Thomas' NHS Foundation Trust, London, UK

ARTICLE INFO

Article history:
Received 29 June 2011
Accepted 6 November 2011
Available online 14 January 2012

ABSTRACT

Background: The Physiological Profile Assessment (PPA) assesses falls risk in older adults by measuring impairments most associated with multiple falls. To date, no study has investigated the change in PPA impairment profile with age.

Objective: To describe impairment profiles, by age and ability to complete the postural sway measure, of older adults fallers.

Participants: We note that 885 older adults referred to multidisciplinary falls clinics located within two inner London boroughs (UK).

Methods: Anonymised data was extracted from the PPA falls risk database. For comparisons, data was grouped by gender, age, and ability to complete the postural sway test.

Results: There were significant differences between all age groups in PPA falls risk, edge contrast sensitivity, quadriceps strength (Quad), postural sway and reported falls within the previous year ($P < 0.01$). The oldest age group (90+) had the highest PPA falls risk ($P < 0.01$), yet reported significantly less falls than the youngest age group (60 to 69; $P < 0.05$). There was significant variability in test results, with younger age groups displaying greater variability across PPA measures, and older age groups displaying more consistency ($P < 0.05$); 15.1% ($n = 134$) of patients that were able to perform the postural sway measure received a higher risk score for this test than those unable to complete the task.

Conclusions: Greater variability in younger age groups indicates that specific impairments may provide the cause of falls, whereas widespread global reduction in function and frailty may provide the cause for falls in the older age groups. The postural sway scoring does not reflect ability to perform the test.

© 2011 Elsevier Masson SAS and European Union Geriatric Medicine Society. All rights reserved.

1. Introduction

Falls are a major cause of disability and the leading cause of injury related death in people over 75 in the UK. In the UK, approximately one third of people over 50 have at least one fall each year, with incidence rates higher in women than in men and increasing rates with advancing years [1,2].

It is widely accepted that there are incremental age-related decreases in many physiological systems including peripheral sensation, vision, strength and vestibular function which may have a detrimental effect on balance function [3–5]. Many falls risk assessment tools examine functional ability, which is generally limited by age related decreases in function which in turn may lead to impaired balance. The Short Form Physiological Profile Assessment (PPA) [6] was developed to assess falls risk by identifying impairments in key physiological measurements

irrespective of health conditions. These tests act individually as predictors for multiple falls in older adults, and, in combination, have a reported ability to identify 75% of multiple fallers in prospective studies [7–9]. These measures are: edge contrast sensitivity, measured using the Melbourne Edge Test (MET) which requires identifying the orientation of a line separating two semi-circles of varying contrast; hand reaction time (Rhand) using a button press paradigm; knee joint proprioception (Prop) using a joint matching test; maximal isometric quadriceps strength (Quad) and postural sway when stood on foam with eyes open. These scores are standardised for age and sex and combined to compute a falls risk score, of which positive values indicate a higher risk for falls [6]. The developmental work for this tool has published results regarding differences between fallers and non-fallers, the relative contributions of each test to risk and PPA falls risk in different populations of patients, but no data regarding the variations in impairment profile which may occur with age has been published [6,9–11]. These impairment profiles may be clinically important, as many UK falls clinics provide standardised strength and balance training, as recommended by the National Institute for Clinical

* Corresponding author. Room 311, Shepherd's House, Centre of Human and Aerospace Physiological Sciences, School of Biomedical Sciences, King's College London, Guy's Campus, London, UK; 321 TEL.

Excellence [12] in a structured group rehabilitation programme to fallers, irrespective of age.

The aim of this study is to therefore identify the contributions of different PPA impairments to the patients' risk profiles by age and discuss findings in regards to falls rehabilitation programmes.

2. Methods

Anonymised retrospective data from the PPA Falls Risk calculator database (www.powmr.edu.au/fbng) entered from three of the four clinic sites of the Southwark and Lambeth Integrated Care Pathway for Fallers (SLIPS) were collated (one site omitted due to difficulties accessing data). Inclusion criteria were:

- age 60 years or older;
- initial assessment PPA only, not follow-up;
- complete datasets.

Out of 1170 entries made during the time window inspected, 885 fulfilled these criteria (75.6%). Of the excluded cases 64% were duplicate entries, 14% were incorrectly entered onto the database, 13% were follow-ups and 9% were less than 60 years of age.

Within SLIPS, the PPA is administered by physiotherapy staff in compliment to a comprehensive medical assessment of visual acuity, cardiac function, tests for focal neurology and medication review. The PPA is administered in patients with a Timed Up and Go (TUG) time of more than 15 s or an inability to perform the TUG, as was previously reported to be predictive of high PPA falls risk in SLIPS patients [13] and therefore in need of more targeted therapeutic interventions.

Raw data for each component test from the PPA is entered onto the web-based PPA falls risk calculator database alongside age, gender and the number of self-reported falls within the past 12 months.

2.1.1. Statistical analyses

Extracted data on self-reported falls rate, raw individual measure results and the (weighted) computed total PPA falls risk score were entered into SPSS version 16 (SPSS Inc.) for analysis. Descriptive data for age groups (median and range) of the total sample were determined. Differences in gender composition were assessed using the χ^2 test. Data was not normally distributed, therefore non-parametric statistics were utilised.

Due to the high proportion of subjects (43.3%) unable to perform the postural Sway test, thus receiving a default score of 2

standard deviations (SD) from the norm, data was stratified and re-analysed as those who completed the test with a sway area under 2500 mm² (less than 2 SD), completed the test in greater than 2500 mm² (greater than 2 SD) and were unable to perform the test. Kruskal-Wallis tests were used to assess for differences between groups based on age and ability to complete the postural Sway test. Post-hoc analysis was performed using multiple Mann-Whitney tests with Bonferroni correction, with an alpha value of $P < 0.05$ for all comparisons [14]. Higher scores in MET and Quad, and low scores in proprioception, reaction time, sway, falls risk and reported falls indicate less impairment.

To compare variability in results between age groups and those able to complete the postural Sway test, firstly the raw data was standardised by converting each variable to a Z score based on the whole test population. The SD of the five PPA Z score measures was then computed for each individual to give a measure of variability across all measures. The Kruskal-Wallis test was used to assess variability in the mean ranks of SD between all age groups.

3. Results

3.1. Gender comparisons

At all sites, more women than men attended the clinics: total 639 females (72.2%, $P < 0.01$), site A, $n = 411$ (71.3%), site B, $n = 185$, (76.8%), site C, $n = 289$, (73.4%).

Overall, males had greater Quad ($P < 0.01$) and reported more falls than females ($P < 0.05$). However, no significant differences were noted when assessing across age groups and male and female data were combined for further analyses to increase power for statistical analysis.

3.2. Comparisons according to age group

Table 1 provides raw data for all PPA measures by age group. Significant differences were noted between age groups for overall PPA falls risk, number of reported falls and for three PPA test measures: MET, Quad and Sway ($P < 0.01$).

Post-hoc analysis revealed that the 60 to 69 age group reported significantly more falls in the previous 12 months compared to all other groups ($P < 0.01$). The 90+ age group had a significantly higher falls risk score compared to all other age groups ($P < 0.01$), lower Quad than the 70 to 79 age group ($P < 0.01$) and greater sway than the 70 to 79 ($P < 0.01$) and 80 to 89 ($P < 0.01$) groups. The 90+ age group also had significantly worse MET scores compared

Table 1

Median scores and ranges for all subjects according to age group for component test of the physiological profile assessment (PPA), physiological profile assessment falls risk and number of self-reported falls in the previous 12 months.

Decade		MET (dB)	Prop (Deg)	Quad (kg)	Stiband (mm)	Sway (mm ²)	Falls Risk	Previous Falls (n)
60–69 (n=88)	Median	19 ^{a,b}	2.8	1.5	3492.5	2500	2.735 ^b	4
	Range	1–24	0.1–14.8	3–48	18.11–890	180–8778	–0.11–7.14	0–4
70–79 (n=315)	Median	19 ^{a,b}	2.8	1.6 ^c	340.1	2500 ^b	2.67 ^a	3 ^c
	Range	1–24	0.1–16.8	2–46	19.83–1000	11.9–16800	–0.89–7.55	0–4
80–89 (n=388)	Median	18 ^a	2.8	1.5	356.5	2500 ^b	2.985 ^b	3 ^c
	Range	1–24	0.1–13.8	1–48	15.88–1000	2.8–2400.0	–0.91–7.77	0–4
90+ (n=96)	Median	16	2.8	1.4	356.5	2500	3.455	3 ^c
	Range	1–24	0.4–8.4	1–32	21.78–826	1.90–8875	–0.43–6.74	0–4
Total (n=885)	Median	18 ^a	2.8	1.5 ^c	353.4	2500 ^b	2.91 ^b	3 ^c
	Range	1–24	0.1–16.8	1–48	15.88–1000	2.8–2400.0	–0.91–7.77	0–4

^a Significantly different to 80 to 89 age group ($P < 0.05$).

^b Significantly different to 90+ age group ($P < 0.05$).

^c Significantly different to 60 to 69 age group ($P < 0.05$).

^d Significant difference between all age groups ($P < 0.01$).

to all other groups ($P < 0.01$) and the 80 to 89 group performed significantly worse than the two younger groups ($P < 0.01$).

The SD of the normalised PPA measures (Z scores) varies with age, with younger age groups having significantly greater variation across test measures than the older age groups ($P < 0.05$, 3 DF). The mean normalised SD for the 60 to 69, 70 to 79, 80 to 89 and 90+ age groups respectively were 0.92 (0.49), 0.94 (0.5), 0.88 (0.52) and 0.79 (0.55).

3.3. Comparisons according to ability to perform Sway test

A large proportion of patients were unable to stand on foam with eyes open for 30 s ($n = 383$; 43.3%) and received the default score of 2500 mm². Three hundred and sixty-eight (41.6%) patients performed the Sway test in under this and 15.1% ($n = 134$) performed it in greater than 2500 mm². Therefore, 15.1% of subjects receive a falls risk score for this measure higher than those unable to perform the test, and who functionally have poorer balance. When stratifying patients into ability to complete and performance on the Sway test, significant differences were noted between all three groups across all PPA measures, falls risk and age ($P < 0.01$). Post-hoc analysis identified that participants able to complete the test in under 2500 mm² had significantly better MET, Prop, Rthand and lower falls risk ($P < 0.05$) scores compared to those completing the test in over 2500 mm². There were no differences in age or number of self-reported falls.

Individuals unable to perform the test performed significantly worse across all PPA measures, had higher falls risk, were older than those performing the test in under 2500 mm² ($P < 0.05$) and had significantly weaker isometric Quad compared to those performing the test in greater than 2500 mm² ($P < 0.05$). Raw data is presented in Table 2.

When assessing variation in SD across the remaining four PPA measures, the mean SD for those able to perform the Sway test in under 2500 mm², greater than 2500 mm² and unable to perform are 0.89 (0.45), 0.95 (0.52) and 0.94 (0.52), respectively. No significant difference was noted between the three groups in SD variability.

4. Discussion

This study aimed to compare the PPA falls risk, variability of PPA measures, individual impairments between age groups of patients attending an integrated falls service and to investigate the ability of older adults to perform the Sway test. Findings showed significant differences in PPA measures between age groups. The discussion will focus on two main themes:

- differences in PPA test measures and variability between age groups;
- ability of older adults to complete the postural sway measure of the PPA test.

5. Differences in Physiological Profile Assessment (PPA) test measures and variability between age groups

Older age groups performed significantly worse and had significantly higher PPA falls risk than younger groups, but reported fewer falls. Conversely, younger age groups better (with lower PPA falls risk) yet reported greater numbers of falls.

Impairment variability changes with age. Greater variability is noted in younger individuals (60 to 69 and 70 to 79), while a concomitant reduction in variability and global reduction in function is noted with advancing years. This may indicate that in older adults, a consistent reduction in function (associated with frailty) across multiple measures results in impaired balance function, and therefore increases falls risk. However, greater variability in the younger age groups may be associated to specific disease processes and as a result inconsistent but specific PPA impairments may account for the increased variability and increased falls rate. The PPA has previously been shown to identify changes in gait parameters in older adults [15] but further measures of gait and/or balance such as preferred gait speed, tandem walk or single leg stand would have provided a useful comparison between groups to correlate PPA measures with functional balance performance. However, these tests are not routinely used in the study falls clinics and so data is not available. Also, the collected clinical information used to direct patient management and rehabilitation such as stroke, diabetic neuropathy, or postural hypotension would have enriched our study data. However, this clinical data was not recorded systematically enough for inclusion in this study.

Differences in reported falls history and variability in PPA measures with age may be due to any number of factors associated with falls in older adults which are not directly assessed by the PPA including cognitive impairment, maladaptive behavioural patterns associated with fear of falling [16] or impairments in vestibular function.

Retrospective collection of falls history, as in our study, may influence subject recall [2] and although falls recall over the previous 6 months is reasonably reliable, prospective data with consistent definitions is better [17]. However, self-reported falls data within the SLIPS clinics is collected by numerous clinicians with no standardised phrasing of questions regarding falls history or definition of falls. The inevitable inconsistency may have affected the accuracy of the falls report rate which could also be

Table 2

Median scores and ranges of physiological profile assessment (PPA) measure scores, age and previous falls for all subjects according to ability to perform the Sway test of the physiological profile assessment.

Sway		MET (dB)	Prop (Deg)	Quad (kg)	Rthand (ms)	Falls Risk	Previous Falls (n)	Age (yrs)
Able – less than 2500 ($n = 368$)	Median	19 ^a	2.4 ^b	18.8 ^a	31.9 ^b	1.9 ^{ab}	3.0	80 ^b
	Range	1.0–24.0	0.1–16.8	2.0–46.0	15.78–10.00	–0.91–7.6	0.0–4.0	60–98
Able – greater than 2500 ($n = 134$)	Median	18.0	2.8	17 ^a	35.75	3.9	3.0	80.0
	Range	1.0–24.0	0.1–14.8	3.0–48.0	20.4–62.95	1.1–7.8	1.0–3.0	60–101
Unable to perform ($n = 383$)	Median	17.0	3.2	14.0	36.22	3.5	3.0	82.0
	Range	1.0–24.0	0.1–12.0	1.0–48.0	19.63–99.20	1.2–7.3	0.0–4.0	60–98
Total ($n = 885$)	Median	18.0 ^c	2.8 ^c	15.0 ^c	35.14 ^c	2.9 ^c	3.0	81 ^c
	Range	1.0–24.0	0.1–16.8	1.0–48.0	15.98–10.00	–0.9–7.7	0.0–4.0	60–101

^a Significantly different to those able to perform in greater than 2500 mm ($P < 0.05$).

^b Significantly different to those unable to perform sway task ($P < 0.05$).

^c Significantly different across groups ($P < 0.01$).

influenced by cognition. Older fallers with cognitive impairment under-report falls rate and perform worse than age-matched controls in the PPA [10]. Thus, cognition may have contributed to our results as the non-faller group had a higher PPA falls risk.

Lifestyle choices for the older age groups who may have restricted their daily movements and activities due to postural instability, possible previous falls, and fear of falling [16] may have also influenced results. However, cognitive function, balance confidence and ADL performance were not assessed in this study; and as such no conclusions can be drawn regarding whether these factors contribute to the current findings. Therefore, our results need to be interpreted with caution.

Many patients with confirmed vestibular disorders fall and are at risk for injury [18,19]. The 2001–2004 US National Health and Nutrition Survey showed that 69 million (35.4%) Americans over age 40 had vestibular dysfunction and the odds significantly increased with age [20]. Furthermore, studies consistently report that older adults referred for a falls risk assessment or presenting to an Emergency Department after a fall have impaired vestibular function on clinical testing [21–25]. Vestibular function is not routinely tested in our SLIPS clinics, and no standardised validated approach exists in the falls literature or NICE guidance. Inquiry about dizziness or vertigo is diagnostically inadequate as patients either do not report these symptoms [21,22] or report similar levels to age-matched non-fallers [26]. In addition, benign paroxysmal positional vertigo (BPPV), which accounts for 17 to 42% of patients with vertigo, is often unrecognised in older adults [22] due to an atypical presentation of unsteadiness or dizziness as opposed to the typical history of brief vertigo attacks (<30 s) triggered by a change in head position. It is suggested that vestibular function testing may strengthen falls risk assessment, prevention, and rehabilitation.

6. Clinical Validity of the Physiological Profile Assessment (PPA) sway measure

Those able to perform the Sway test in less than 2500 mm² perform significantly better across all PPA measures (except Quad in greater than 2500 mm²) and have a lower falls risk than all other groups.

There is a trend for those unable to perform the Sway test to perform worse on individual PPA measures, yet have lower PPA falls risk than those that perform the Sway test in greater than 2500 mm². Those able to complete the test are receiving higher PPA falls risk scores as their sway area is greater than the default score ($2 \times SD$) given to those unable to complete the task. This artificially elevates their score and incorrectly classifies those able to complete the task as at higher risk than those that cannot maintain stability on foam with eyes open. This would cast doubt on the PPA scores of 58.4% of patients tested in this clinic, limiting the usefulness of the PPA as a measure of postural stability.

7. Conclusions

Younger individuals reported significantly more falls yet had significantly lower falls risk than the oldest age group which reported significantly less falls. The oldest (80+) adults have reduced variability in PPA measures consistent with global reductions in function and frailty; younger individuals have significantly greater variability across PPA measures, indicating that focal pathology within specific PPA test measures may be the cause for falls. It is suggested that current findings be considered when organising falls rehabilitation programmes for younger and older individuals.

Individuals that complete the Sway test in greater than 2500 mm² receive higher scores for sway than those unable to maintain stability in this test. This artificially elevates the sway score contributing to overall PPA falls risk, increasing PPA falls risk compared to an individual that is unable to complete the Sway test.

The PPA incorrectly classifies 58.4% ($n = 302$) of subjects on the sway measure. Therefore, the clinical validity of the PPA may be questionable.

8. Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References

- [1] O'Neill TW, et al. Fall frequency and incidence of fatal forearm fracture in the UK. *J Epidemiol Community Health* 1995;49(6):597–601.
- [2] Fleming J, Matthews DR, Brayne C. Falls in school and old age: recalled falls and prospective follow-up of over-90-year-olds in the Cambridge City over-75 cohort study. *BMJ Geriatr* 2008;33:5.
- [3] Lord SR, Clark RD, Webster IW. Postural stability and associated physiological factors in a population of aged persons. *J Gerontol* 1981;36(3):M69–76.
- [4] Rao AD, et al. Effect of altered sensory conditions on multivariate description of human postural sway. *Exp Brain Res* 1986;122(2):185–95.
- [5] Lord SR, Ward JA. Age-associated differences in sensorimotor function and balance in community dwelling women. *Age Ageing* 1994;23(5):452–60.
- [6] Lord SR, Menz HB, Tiedemann A. A physiological profile approach to falls risk assessment and prevention. *Phys Ther* 2001;81(3):217–32.
- [7] Lord SR, et al. Postural stability, falls and fractures in the elderly: results from the Dubbo osteoporosis epidemiology study. *Med J Aust* 1994;160(11):694–5 [688–691].
- [8] Lord SR, Clark RD, Webster IW. Physiological factors associated with falls in an elderly population. *J Am Geriatr Soc* 1991;39(12):1194–200.
- [9] Lord SR, et al. Physiological factors associated with falls in older community-dwelling women. *J Am Geriatr Soc* 1994;42(10):1110–2.
- [10] Lorchbach SR, et al. Physiological falls risk assessment in older people with Alzheimer's disease. *Dement Geriatr Cogn Disord* 2007;24(4):260–5.
- [11] Scabbo SM, et al. Older women with age-related muscular degeneration have a greater risk of falls: a physiological profile assessment study. *J Am Geriatr Soc* 2008;56(5):800–7.
- [12] NICE. Clinical practice guideline for the assessment and prevention of falls in older people. ed. N.I.C. Excellence. Royal College of Nursing; 2004.
- [13] Whitney JC, Lord SR, Cline JC. Streamlining assessment and intervention in a falls clinic using the timed up and go test and physiological profile assessment. *Age Ageing* 2005;34(6):567–71.
- [14] Field AP. Discovering statistics using SPSS: (and sex, drugs and rock music). 2nd ed. Introducing statistical methods. London: Sage Publications; 2005. xxviii, p. 778.
- [15] Callaway ML, et al. A population-based study of sensorimotor function and falling risk in older people. *Age Ageing* 2008;38(3):290–5.
- [16] Bruce DG, Devine A, Prince RL. Recreational physical activity levels in healthy older women: the importance of fear of falling. *J Am Geriatr Soc* 2002;50(1):94–8.
- [17] Gatz DA, Figeles T, Rubenstein LZ. Monitoring falls in cohort studies of community-dwelling older people: effect of the recall interval. *J Am Geriatr Soc* 2005;53(12):2190–4.
- [18] Herdman SJ, et al. Falls in patients with vestibular deficits. *Am J Otol* 2000;21(6):947–51.
- [19] Whitney JC, Thalak MT, Marchetti GF. The dynamic gait index relates to self-reported fall history in individuals with vestibular dysfunction. *J Vestib Res* 2000;10(2):99–105.
- [20] Agrawal V, et al. Disorders of balance and vestibular function in US adult data from the National health and nutrition examination survey, 2001–2004. *Arch Intern Med* 2009;169(10):933–44.
- [21] Linton J, et al. Postural vertigo in a falls service. *Age Ageing* 2008;37(5):585–8.
- [22] Linton J, et al. Benign paroxysmal positional vertigo: clinical characteristics of dizzy patients referred to a Falls and Syncope Unit. *QJM* 2005;98(5):357–64.
- [23] Kristoforoff SR, Jamlo G, Magnusson M. Asymmetric vestibular function in the elderly might be a significant contributor to hip fractures. *Scand J Rehabil Med* 2000;32(2):56–60.
- [24] Kristoforoff SR, et al. Observation of vestibular asymmetry in a majority of patients over 50 years with fall-related wrist fractures. *Acta Otolaryngol* 2001;121(4):461–5.
- [25] Zar OH, Camelli YN. E. Correlation between vestibular function and hip fracture following falls in the elderly: a case-controlled study. *Physiotherapy* 2006;92:208–13.
- [26] Murray KJ, et al. A pilot study of falls risk and vestibular dysfunction in older fallers presenting to hospital emergency departments. *Disabil Rehabil* 2005;27(9):489–90.